Hindawi
Advances in Civil Engineering
Volume 2023, Article ID 6615183, 12 pages
https://doi.org/10.1155/2023/6615183

Research Article

The Effect of Superabsorbent Polymer on Fair-Faced Concrete Performance Based on White Cement

Jun Shi[1] **Zhangbao Wu**[2] **Jinping Zhuang**[3] **Rong Chen**[4] **Tongran Zhu**[5] **Chenzheng Yuan**[6] **and Huixia Li**[3]

[1]*Fujian Communications Planning & Design Institute Co., Ltd., Fuzhou 350000, China*
[2]*Fujian Jiuding Construction Group Co., Ltd., Fuzhou 350000, China*
[3]*School of Civil Engineering, Fujian University of Technology, Fuzhou 350118, China*
[4]*Hengchao Construction Engineering Group Co., Ltd., Xiamen 361000, China*
[5]*Beijing Yihuida Architectural Concrete Construction Engineering Co., Ltd., Beijing 100010, China*
[6]*School of Management, Fujian University of Technology, Fuzhou 350118, China*

Correspondence should be addressed to Jinping Zhuang; 19781208@fjut.edu.cn

Received 14 December 2022; Revised 28 March 2023; Accepted 10 April 2023; Published 27 April 2023

Academic Editor: Adewumi Babafemi

Introducing superabsorbent polymer (SAP) into white fair-faced concrete can achieve the purpose of internal curing, which is beneficial to the popularization and application of white fair-faced concrete. The effects of the SAP mixture and internal curing water content on the properties of white fair-faced concrete were investigated macroscopically through the indexes, including slump, electric flux, standard cube compressive strength, and tensile splitting strength. The mechanism of these influence laws was further analyzed by scanning electron microscope (SEM). The results show that the slump increases with the increase of SAP content and internal curing water; the incorporation of SAP can significantly reduce the electric flux of white fair-faced concrete and improve its durability; with the increase of SAP admixture and internal curing water content, the compressive strength of white fair-faced concrete decreases, which has a significant impact on the early compressive strength; the addition of SAP is beneficial to the improvement of the tensile properties and tensile-compression ratio of white fair-faced concrete. When the SAP content is 0.2%, and the internal curing water is ten times the mass of SAP, the optimal performance of white fair-faced concrete can be achieved; the water released by the SAP promotes the secondary hydration reaction, which can refine the internal structure of white fair-faced concrete.

1. Introduction

Fair-faced concrete refers to the concrete formed at one time and directly uses the original concrete pouring surface as the decorative surface [1]. Because it exposes the concrete as the decorative surface, it has higher requirements on the appearance of the concrete and is more susceptible to external environmental erosion [2, 3]. Compared with ordinary fair-faced concrete, white fair-faced concrete has excellent appearance properties and a wide range of application prospects [4, 5]. However, the use of white Portland cement has the problems of high early hydration heat and a fast hydration reaction rate [6, 7], which may easily lead to premature concrete cracking. At the same time, to increase the compactness inside the concrete to improve the corrosion resistance, a lower water-cement ratio is generally used, and a low water-cement ratio will lead to incomplete cement hydration [8]; when cement is not fully hydrated, concrete will experience significant autogenous shrinkage [9, 10]. The dense internal structure facilitates erosion resistance but can limit the movement and free shrinkage of water molecules in concrete, which increases the risk of cracking [11–13]. When the tensile stresses generated by the self-shrinkage are more significant than the tensile strength of the concrete itself, cracks will develop inside the concrete, further exacerbating the risk of cracking. While improving the corrosion resistance, the research on improving the tensile strength and avoiding its cracking is essential for popularizing and applying white fair-faced concrete.

Traditional surface curing water is challenging to penetrate fair-faced concrete with dense internal structures, and it is difficult to achieve a good curing effect [14]. Therefore, it is necessary to provide curing water from the inside. The internal curing technology incorporates a high-water absorption material into the concrete mixture, which absorbs a large amount of water during the concrete mixing process or before mixing [15]. During the hardening process of concrete, the internal humidity decreases, and the superabsorbent material slowly releases the absorbed water, maintains the internal moisture of the concrete, and plays the role of internal curing [16]. Internal curing technology can effectively reduce the risk of cracking and improve the durability of concrete [17–19]. The commonly used internal curing technologies include lightweight aggregate (LWA) internal curing and superabsorbent polymer (SAP) internal curing [20, 21]. LWA can effectively reduce the risk of concrete cracking, but its low strength will significantly weaken the mechanical strength and affect the working performance of concrete, such as its durability [22–24]. In contrast, SAP can not only prevent concrete from cracking but also has advantages in air entrainment and impermeability and has little effect on the strength [25, 26]. The International Union of Laboratories and Experts in Construction Materials (RILEM) published a report on the application of SAP, which comprehensively expounded the effect of SAP on concrete [27], which is an ideal material for application in white fair-faced concrete.

Many scholars have researched the application of SAP internal curing technology. Shen et al. [28–30] systematically studied the effect of SAP on the early autogenous shrinkage properties of concrete, indicated that SAP can effectively reduce the autogenous shrinkage of concrete, and established the autogenous shrinkage prediction model of SAP concrete. Kong and Zhang [31] studied the effect of SAP content on the autogenous shrinkage and drying shrinkage impacts and found that the SAP content is closely related to the internal curing effect. The autogenous shrinkage and drying shrinkage of concrete are the main causes of nonload cracks in concrete, and the use of SAP has a significant shrinkage reduction effect on the autogenous shrinkage and drying shrinkage of concrete. Jiang et al. [32] studied the effect of SAP on the hydration of concrete using XRD and DTA-TG, and concluded that SAP would retard the hydration of concrete in the early stage (0–7 days), but would have little effect on the hydration in the middle and late stage (7 days–28 days), and that a reasonable amount of admixture would not affect the mechanical properties. Jensen and Bentz [33] found that the incorporation of SAP can provide the effect of entrained air and enhance the frost resistance of concrete. Sun et al. [34] conducted a comparative test of the influence of SAP and mineral fine aggregate on the impermeability of concrete. They indicated that the impermeability of SAP concrete is more substantial than ordinary concrete. Ouattara Coumoin et al. [35] studied the effect of dry-wet cycle conditions on the internal curing of SAP. And the results showed that dry-wet cycle conditions greatly impacted the internal curing of SAP. With the incorporation of SAP, the durability of high-performance concrete was improved. Chidiac et al. [36] used nuclear magnetic resonance technology to quantitatively analyze the water absorption, water release, and internal curing efficiency of SAP. Olawuyi and Boshoff [37] used 3D volume analysis to investigate the effects of SAP content, particle size, and curing age on the distribution of concrete pores. Shen et al. [38] studied the impact of Barchip fibers and SAP on concrete's early mechanical properties and crack resistance and found that the incorporation of SAP increased the early crack resistance ability. Karim [39] reviewed the relevant literature on the effect of internal curing on concrete. They pointed out that the particle size of SAP would affect the efficiency of internal curing. Based on the Power model [40], Jensen and Hansen [41] also clearly pointed out that the content of internal curing water needs to comprehensively consider the content of SAP, the particle size, and the saturation state of SAP to exert the optimal internal curing effect.

In summary, incorporating SAP in the internal curing method is the preferred method to make the internal structure of concrete dense and improve the anticracking performance. Research on referring SAP to white fair-faced concrete is somewhat limited. The effects of SAP dosage and internal curing water on white fair-faced concrete need further study.

Based on the experimental results, this paper investigates the effects of slump on the flowability, electric flux on the durability, and standard cube compressive and tensile splitting strength tests on the mechanical properties of white fair-faced concrete macroscopically, and explains the mechanism of macroscopic performance influence microscopically by scanning electron microscope (SEM) testing. The research results can provide a theoretical basis and application support for SAP in white fair-faced concrete.

2. Experiment

Seven groups of concrete with different mix ratios were designed, including ordinary fair-faced concrete, white fair-faced concrete, and white fair-faced concrete with different SAP admixtures and internal curing water contents. The effects of SAP admixture and internal curing water on the durability and mechanical properties of white fair-faced concrete were studied.

2.1. Materials. This experiment used white Portland cement provided by Albo Portland (Anqing) Co., Ltd., with a strength grade of 42.5 N and a fineness of 300 mesh; Class II fly ash; and ordinary Portland cement, which the chemical composition of the cementitious material is shown in Table 1. The fine aggregate is medium sand with a fineness modulus of 2.7; the coarse aggregate is graded gravel particle with particle sizes of 5–10 mm and 10–25 mm; the water reducer is polycarboxylate superplasticizer; the SAP was produced by the Yixing Kexinde Chemical Co., Ltd. has a particle size of 30–60 mesh (0.6 mm–0.25 mm). The main component of SAP is low cross-linked polyacrylic acid sodium salt, and the main performance indexes are shown in Table 2.

Table 1: Chemical composition of cementitious materials/%.

Component	CaO	SiO_2	Al_2O_3	MgO	Fe_2O_3	K_2O	LOI
White Portland cement	62.79	20.75	3.22	2.53	0.25	1.34	1.96
Ordinary Portland cement	52.84	14.24	5.41	1.80	2.46	0.89	9.87
Fly ash	3.32	59.80	28.99	0.52	4.28	1.31	2.28

2.2. Mix Proportion of Fair-Faced Concrete. The mix proportion is the core of the overall quality of white fair-faced concrete, which needs to meet the flowability and uniform appearance and color requirements. The strength grade of white fair-faced concrete configured in this paper is C50, and the slump requirement is (180 ± 30) mm. Incorporating superabsorbent polymer requires the introduction of internal curing water, which is generally ten times the mass of the superabsorbent polymer [42] for ordinary concrete. Different internal curing water magnifications are set to investigate the effect of internal curing water on the performance of white fair-faced concrete. The mix proportion of the specimens is shown in Table 3. The first group of letters C in the specimen numbers in Table 3 stands for ordinary fair-faced concrete specimens, and AC stands for white fair-faced concrete specimens; the second group of 0.2, 0.3, and 0.4 represents the content of SAP (0.2%, 0.3%, and 0.4% of the cementitious material, respectively); the third group of 5, 10, and 15 represents the internal curing water ratio, which is a multiple of the SAP mass. In Table 3, With the internal curing water ratio of 10, to study different content of SAP using the compare groups of AC-0.2-10, AC-0.3-10, and AC-0.4-10; with the content of SAP of 0.2%, to study different curing water ratio using the compare groups of AC-0.2-5, AC-0.2-10, and AC-0.2-15.

Preparing white fair-faced concrete with SAP needs to make the SAP absorbing water according to the preset internal curing water amount. After the white Portland cement, fly ash, gravel, and fine aggregates are mixed for 1 minute, and the materials are uniformly dispersed. Then add the mixing water and water reducing agent and mix for 30 s, and finally add the preabsorbed SAP and mix for 2 min to ensure that the water reducing agent is fully dispersed, while avoiding the absorption of water reducing agent by SAP. The white fair-faced concrete formed by mixing has a uniform appearance, a smooth surface, and whiteness, as shown in Figure 1. The appearance meets the requirements of white fair-faced concrete.

2.3. Slump Test. The slump test can reflect the flowability of concrete. The test steps are carried out according to the *Chinese Standard for Performance Test of Ordinary Concrete Mixtures* (GB/T50080-2016) [43], which can be used to analyze the effect of SAP content and internal curing water content on the workability of white fair-faced concrete.

2.4. Electric Flux Test. On the macro level, it is effective to study the durability of concrete through an electric flux test. The specific test steps and test results processing methods were carried out by the "Chinese Standards for Long-term Performance and Durability of Ordinary Concrete" GBT50082-2009 [44]. This test tests the 28 days electric flux of different types of fair-faced concrete specimens. After standard curing to 7 days before the test, the cylindrical specimen with a diameter of 100 mm and a height of 100 mm is processed into a standard cylindrical specimen with a diameter of 100 mm and a height of 50 mm, making 3 pieces of each type of specimens. The specimens were vacuum-filled after 27 days curing, and the specimens cured for 28 days were put into the test device to detect the total electric flux passing through the specimens under 60 V DC voltage for 6 hours. The influence laws of SAP content and curing water amount on the durability of white fair-faced concrete are analyzed.

2.5. Standard Cube Compressive and Tensile Splitting Strength Tests. The size of the fair-faced concrete specimen is $150\,mm \times 150\,mm \times 150\,mm$. 9 pieces of each type of specimen were divided into 3 groups according to the age, and maintained in a constant temperature and humidity maintenance room for 3 days, 7 days, and 28 days, respectively. The compressive and tensile strengths of the specimens and the numerical treatment of the test results were carried out according to the Chinese standard GB/T50081-2002 [45]. Compressive and tensile splitting strength tests were conducted to analyze the influence of SAP and internal curing water content on the mechanical properties of white fair-faced concrete of different ages.

2.6. SEM Test. The microstructure of white fair-faced concrete was observed by SEM test. The observation samples with a length and width of 1 cm and a thickness of 3 mm were sampled from the AC and AC-0.2-10 specimens with a curing age of 28 days. The microstructural properties and the influence of SAP on the microstructure were analyzed. The macroscopic law mechanism was explained.

3. Test Results and Analysis

3.1. Effect on the Slump. Figure 2 shows the slump of different types of fair-faced concrete. It shows that the slump of white fair-faced concrete is lower than that of ordinary fair-faced concrete; this may be due to the effect of the difference in particle size distribution on the flowability and thus the loss of concrete slump. So, adding white Portland cement is not conducive to the flow properties of concrete, while the slump of white fair-faced concrete would be significantly improved after adding SAP because after water absorption, the SAP can play a lubricating role between the cementitious material and the aggregate and improve the flowability of the white fair-faced concrete. With the increase in SAP content, the slump is larger, and adding SAP can effectively improve the flowability of the white fair-faced concrete.

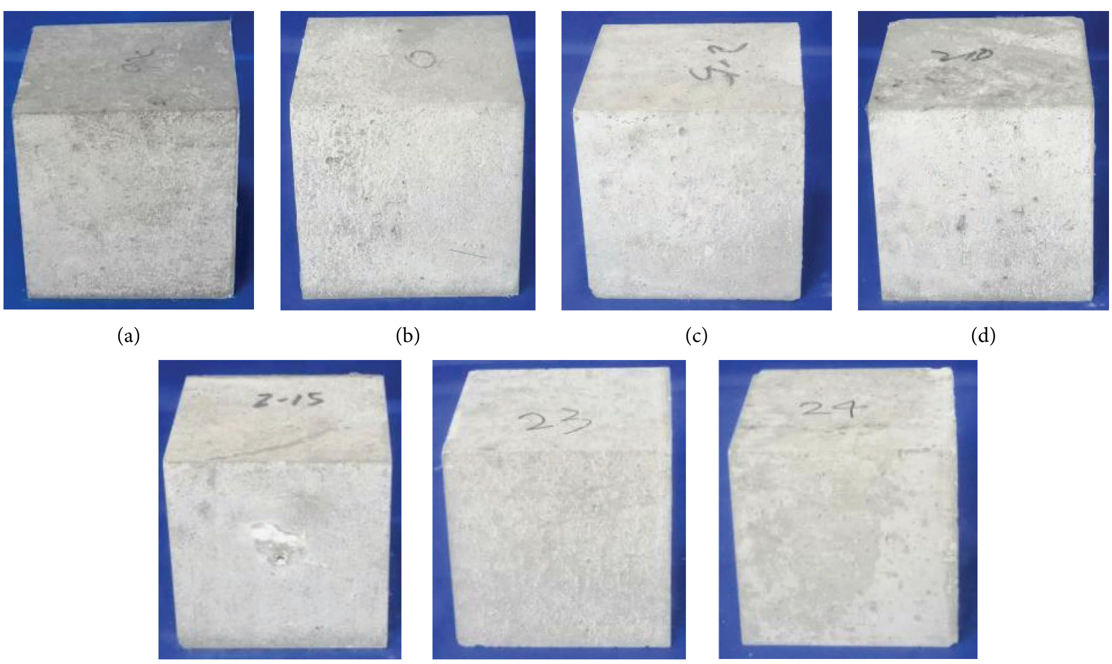
It can be seen from Figure 2(b) that the slump of white fair-faced concrete with the same amount of SAP increases with the increase of the internal curing water ratio. At the same time, due to the rise in preabsorption water, SAP

Table 2: SAP performance indicators.

Materials	Particle size (mm)	Deionized water absorption (g/g)	Water absorption rate (s)	PH	Volume density (g/cm^3)
SAP	0.25–0.6	≥200	≤60 s	6~7	0.6~0.9

Table 3: Mix proportion of concrete (kg/m^3).

Specimen number	White cement	Portland cement	Fly ash	Gravel	Sand	Water	Water reducer	Superabsorbent polymer	Internal curing water
C	0	317	133	1083	752	150	4.6	0	0
AC	317	0	133	1083	752	150	4.6	0	0
AC-0.2-5	317	0	133	1083	752	150	4.6	0.9	4.5
AC-0.2-10	317	0	133	1083	752	150	4.6	0.9	9
AC-0.2-15	317	0	133	1083	752	150	4.6	0.9	13.5
AC-0.3-10	317	0	133	1083	752	150	4.6	1.35	13.5
AC-0.4-10	317	0	133	1083	752	150	4.6	1.8	18



(a) (b) (c) (d) (e) (f) (g)

Figure 1: Appearance of fair-faced concrete: (a) C; (b) AC; (c) AC-0.2-5; (d) AC-0.2-10; (e) AC-0.2-15; (f) AC-0.3-10; (g) AC-0.4-10.

absorbs less water during mixing, and the slump has been improved [46]; the slump of white fair-faced concrete increases with the increased SAP content and internal curing water ratio.

3.2. Effect on Electric Flux. Figure 3 shows the electrical flux of different types of fair-faced concrete. Figure 3(a) shows that the electrical flux of white fair-faced concrete in group AC is higher than that of ordinary fair-faced concrete in group C. This reaction is because the hydration rate of white cement is higher. The slurry pore structure is more likely to form coarse pores, and the porosity is more prominent, which leads to the deterioration of the durability of the concrete. The addition of SAP into white fair-faced concrete greatly influences the electric flux coefficient. Compared with the AC group without SAP, the electric flux of white fair-faced concrete mixed with 0.2%, 0.3%, and 0.4% is reduced by 14.9%, 31.9%, and 24.0%, respectively. This is because the water released by the SAP promotes the secondary hydration reaction inside the white fair-faced concrete. And three components, Ca $(OH)_2$ produced by hydration reactions, SiO_2 from fly ash, and water, react to form the C-S-H crystals, refining the internal pore structure of white fair-faced concrete [47]. And this can effectively cut off the connection between capillaries and limit current electrical passage. The SAP in the white fair-faced concrete can effectively exert its internal curing effect and

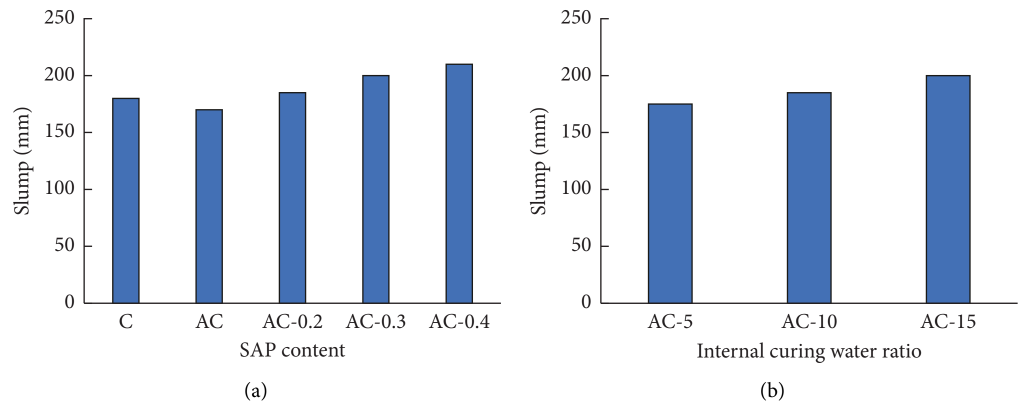


Figure 2: Slump of different types of fair-faced concrete: (a) effect of SAP content; (b) effect of internal curing water ratio.

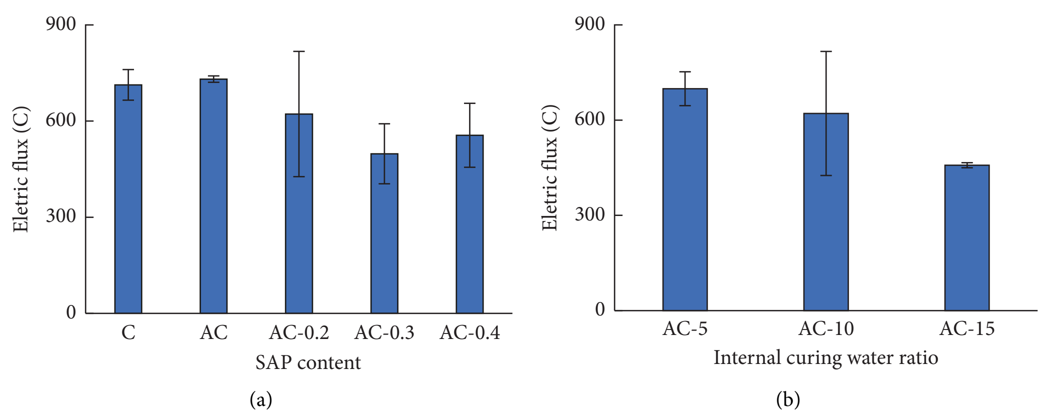


Figure 3: Electric flux of different types of fair-faced concrete: (a) effect of SAP content; (b) effect of internal curing water ratio.

significantly improve its durability. Figure 3(a) also indicates that when the amount of SAP is 0.3%, the decrease in electric flux is the most obvious. In terms of the durability of white fair-faced concrete, adding 0.3% of SAP can significantly improve the performance of white fair-faced concrete.

It can be seen from Figure 3(b) that with the increase of the internal curing water rate, the electric flux of the white fair-faced concrete gradually decreases, and the durability performance gradually improves. Compared with the internal maintenance water volume of 5 times the quality of SAP, the electric flux of 10 times and 15 times the internal maintenance water decreased by 11.2% and 34.5%, respectively, and the overall decrease was pronounced. The more the water storage capacity of SAP is, the sooner the saturation state is reached. When the internal humidity of white fair-faced concrete decreases, the SAP will release more water, and the secondary hydration reaction generates more C-S-H crystals, which refining the internal pore structure of white fair-faced concrete. The higher the value of the internal curing water rate, the more significant the reduction of the electric flux, and the more pronounced the improvement of the durability of the white fair-faced concrete.

3.3. Effect on Mechanic Performance

3.3.1. Effect on Compressive Strength. Figure 4 shows the effect of different SAP contents and internal curing water ratios on the compressive strength of white fair-faced concrete. It can be seen from Figure 4(a) that with the addition of SAP, the 3 days compressive strength of white fair-faced concrete significant decrease occurred. Compared with the AC group, when the SAP content was 0.3%, the compressive strength of white fair-faced concrete decreased from 46.7 MPa to 30.7 MPa, and the decrease was as high as 34.3%. The content of the SAP has a significant effect on the early strength of white fair-faced concrete. In the existing research, adding SAP to ordinary concrete will deteriorate its 3 days strength, but the effect is insignificant. Only at 14 d age does the more obvious deterioration of concrete mechanical properties occur. With the increase of age, the compressive strength of concrete with SAP is the same as that without SAP [48]. Compared with ordinary fair-faced concrete in group C, it can be found that white fair-faced concrete in group AC will generate more C_3A due to hydration, and C_3A has a significant influence on the early strength of concrete, reflecting the characteristics of early

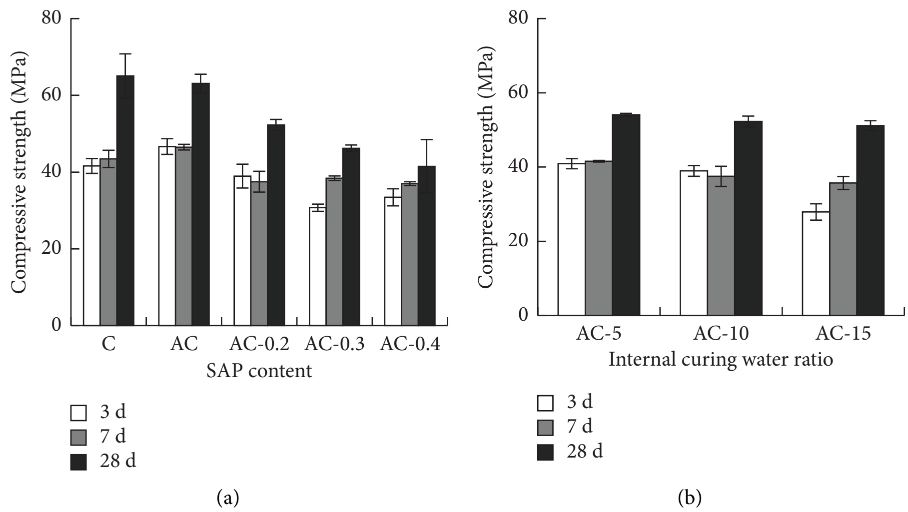


Figure 4: Compressive strength of different types of fair-faced concrete: (a) effect of SAP content; (b) effect of internal curing water ratio.

strength. And the compressive strength of 3 days and 7 days is quite different. Although the 3 days strength of ordinary fair-faced concrete in group C is relatively low, with the increase of curing age, the strength increases significantly from 3 days to 7 days, which also explains why SAP greatly influences the early strength of white fair-faced concrete.

On the one hand, white Portland cement generates more C_3A due to hydration, the hydration reaction speed is fast, the hydration heat is high, the peak hydration heat is reached at 12 h, and the water consumption is large [49]. The incorporated SAP continues to absorb water, which results in the lack of water in the white fair-faced concrete and would delay the hydration process [50]. The lack of water in concrete cannot generate enough C-S-H crystals with a stable structure, and the excess of $Ca(OH)_2$ causes a considerable loss of early strength. On the other hand, SAP water absorption Dimensional expansion occurs, and more pores are formed after water release, further aggravating the deterioration of early strength. Incorporating SAP into white fair-faced concrete requires attention to the substantial decrease in its early compressive strength. The 28 days compressive strength of SAP white fair-faced concrete with a dosage of 0.2%, 0.3%, and 0.4% decreased by 17.1%, 26.8%, and 34.2%, respectively, compared with the no SAP addition specimens. The compressive strength of white fair-faced concrete gradually reduced with the increase of SAP content.

It can be analyzed from Figure 4(b) that the larger the amount of internal curing water preabsorbed by SAP, the more obvious the impact on the compressive strength. The amount of additional curing water will affect the water-cement ratio. And the more water absorbed, the SAP particle will have a bigger volume, and the more pronounced the effect of pores caused by water release, which leads to a further decrease in strength. This law is consistent in the ages of 3 days, 7 days, and 28 days. The internal curing water ratio significantly impacts the performance of white fair-faced concrete. Too little or too much water will affect the flowability of white fair-faced concrete. For the mechanical properties of white fair-faced concrete, considering the influence of the internal curing water amount on the flowability and mechanical properties, it is reasonable to select the curing water amount of 10 times the quality of SAP.

3.3.2. Effect on Tensile Splitting Strength. The effect of SAP content and internal curing water ratio on the tensile splitting strength of white fair-faced concrete is shown in Figure 5. Figure 5(a) shows that the tensile splitting strength of white fair-faced concrete in the AC group is slightly higher than group C. The addition of SAP reduced the tensile splitting strength of white fair-faced concrete in group AC. And tensile splitting strength at the SAP content of 0.2%, 0.3%, and 0.4% at 3 days decreased by 16.9%, 7.7%, and 25.5%, respectively, which is consistent with the reason for the decrease in compressive strength, that is, delaying the hydration process and the pores generated by the water release by SAP.

Figure 5(b) shows the effect of the internal curing water ratio on the tensile splitting strength of white fair-faced concrete. The effect of curing water on the tensile splitting strength is not apparent. The tensile strength of internal curing ratios 5 and 15 is 0.04 MPa and 0.13 MPa, respectively, which shows little difference with the AC-10 group. But with the increase of age, the internal curing water ratio is 10. The tensile splitting strength of group AC-10 is the highest among the three internal curing water ratios.

3.3.3. The Effect on the Tension-Compression Ratio. Under the condition that the designed compressive strength of concrete is met, the higher the tensile-compression ratio of concrete, the higher the tensile strength, and the less likely it is to crack. Take the early 3 days and the standard curing 28 days for analysis. It can be seen that the tensile-compression ratio of white fair-faced concrete in group AC is slightly lower than that of ordinary fair-faced concrete in group C at 3 days, but it increases with age. Compared with ordinary fair-faced concrete in group C, white fair-faced concrete is easier to crack in

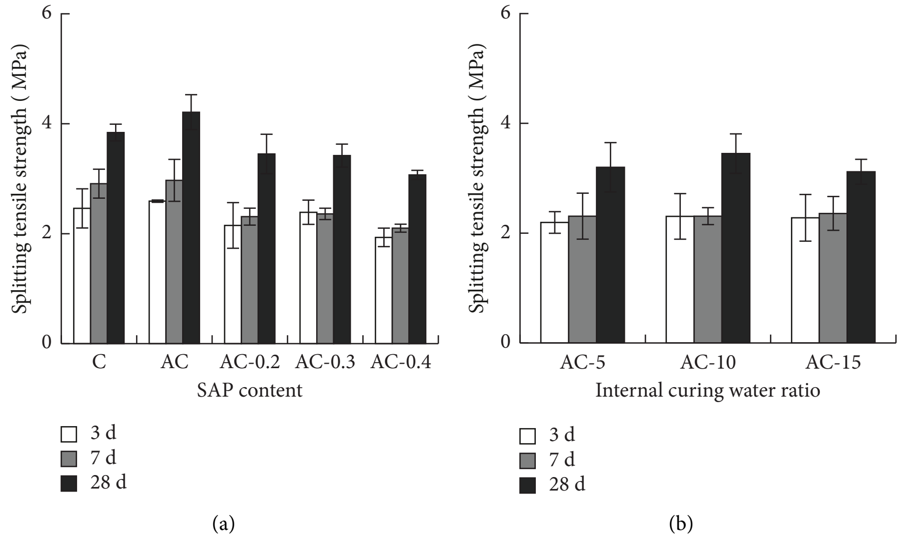


Figure 5: Tensile splitting strength of different types of fair-faced concrete: (a) effect of SAP content; (b) effect of internal curing water ratio.

the early stage under the same design conditions of compressive strength. It can also be seen from the figure that the addition of SAP will affect the tension-compression ratio of white fair-faced concrete. At 3 days, compared with white fair-faced concrete, the addition of SAP is 0.2%, 0.3%, and 0.4%. The ratio changes are −1.8%, 39.3%, 3.6%, and 0.3%. The tensile-compression ratio of white fair-faced concrete increases significantly but greatly weakens the early compressive strength of white fair-faced concrete, which needs attention. At the age of 28 days, the change amplitudes of the tension-compression ratios with the addition of SAP of 0.2%, 0.3%, and 0.4% were −1.5%, 10.5%, and 10.5%, respectively. SAP can play its internal curing role in white fair-faced concrete. Adding 0.3% and 0.4% SAP can effectively improve the tension-compression ratio of white fair-faced concrete, which is beneficial to applying white fair-faced concrete in practical engineering.

It can be seen from Figure 6(b) that the tension-compression ratio is the most ideal when the internal curing water is ten times the mass of SAP, which can rise steadily. Less curing water is not conducive to the performance of white fair-faced concrete. Adding additional curing water will increase the water-cement ratio and deteriorate the mechanical properties of white fair-faced concrete, which is consistent with the law analysis above. It can be improved to prevent cracks in white fair-faced concrete. SAP has good application prospects in white fair-faced concrete.

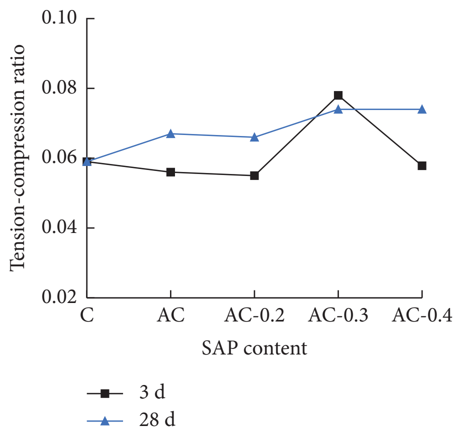
3.4. SEM Microscopic Observation. Select AC and AC-0.2-10 from the test group for SEM microscopic observation. The observation results are shown in Figure 7, from which the effect of SAP on the microstructure of white fair-faced concrete cured for 28 days can be observed. From Figures 7(a) and 7(b) The 16 times magnified micrographs of white fair-faced concrete without SAP and white fair-faced concrete with SAP can be seen that SAP white fair-faced concrete produces more pores due to SAP water release, which increases the porosity of white fair-faced concrete. Thus, it affects the compressive strength of white fair-faced concrete [42], which is the main reason SAP reduces the compressive strength and tensile splitting strength of white fair-faced concrete. Figures 7(c)–7(f) shows that the white-water concrete without SAP and the white-water concrete mixed with SAP are magnified 3000 times and 5000 times, respectively. It can be seen that the white water without SAP The internal structure of the concrete is relatively loose, and there is no gel surrounding the fly ash, and a large number of Ca $(OH)_2$ tabular particles can be seen. The surface hydration reaction of the fly ash is not apparent, and the SiO_2 activation effect is not effectively exerted. The white fair-faced concrete mixed with SAP shows that a large amount of C-S-H gel surrounds the fly ash. There is no significant amount of Ca $(OH)_2$plate-like particles around it, indicating that SAP water release can effectively promote the SiO_2 composition of fly ash to be the same as the Ca $(OH)_2$ reaction to generate C-S-H gel. SAP can effectively play an internal curing role in white fair-faced concrete. That is, to promote the secondary hydration reaction of fly ash and helps to form a dense white fair-faced concrete inside. These further reveal why SAP reduces white fair-faced concrete's electric flux.

4. Predictor Formula of Strength

4.1. SAP White Fair-Faced Concrete Compressive Strength Predictor Formula. The calculation formula of the predicted compressive strength of white fair-faced concrete containing SAP was solved by the least square method. The calculation formula is as follows:

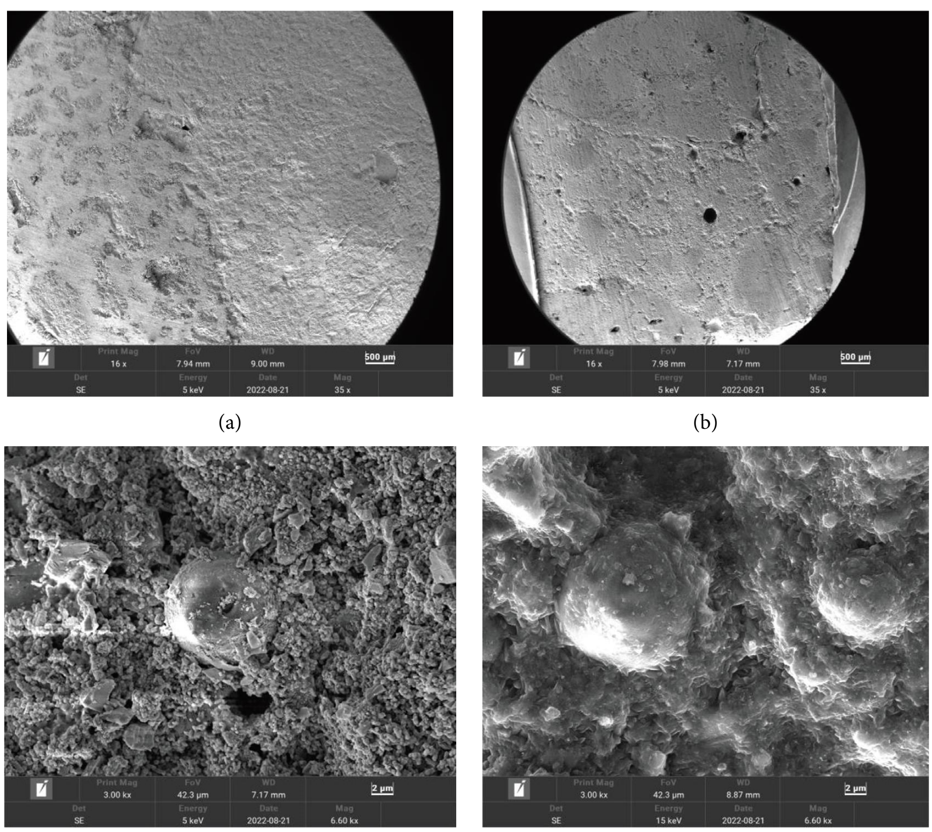
$$f_{cu} = k_1 \cdot k_2 \cdot f_{cu}^{\gamma}. \quad (1)$$

Among the formula, f_{cu} is the compressive strength of white fair-faced concrete containing SAP; $k_1 = 1.12\lambda^{-0.05}$ is the influence coefficient of the internal curing water ratio on



(a) (b)

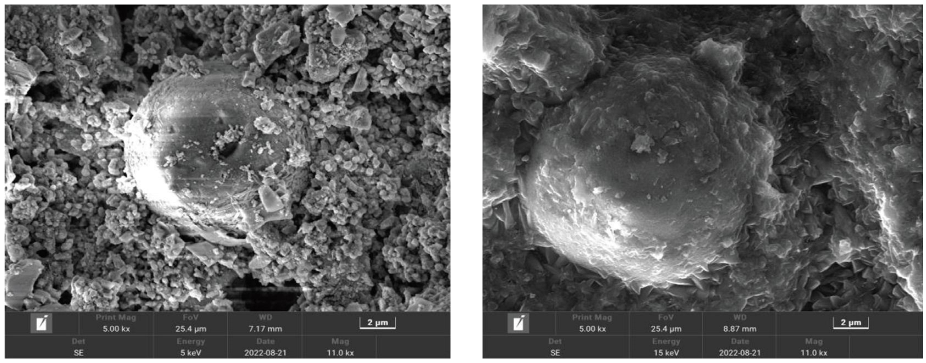
Figure 6: Tension-compression ratio of different types of fair-faced concrete: (a) effect of SAP content; (b) effect of internal curing water ratio.



(a) (b)

(c) (d)

Figure 7: Continued.



(e) (f)

Figure 7: SEM image of 28 days fair-faced concrete: (a) 16x SEM image of group AC; (b) 16x SEM image of group AC-0.2-10; (c) 3000x SEM image of group AC; (d) 3000x SEM image of group AC-0.2-10; (e) 5000x SEM image of group AC; (f) 5000x SEM image of group AC-0.2-10.

the compressive strength of white fair-faced concrete; λ is the internal curing water ratio because only in the case of adding SAP, internal curing water will be introduced, so when the content of SAP is 0, k_1 is taken as 1, $k_2 = -0.8\rho + 1$ is the influence coefficient of the amount of SAP on the compressive strength of white fair-faced concrete; ρ is the content of SAP, $f_{cu}{}^{\gamma}$ is the compressive strength of white fair-faced concrete.

The comparison between the compressive strength of SAP white fair-faced concrete calculated by the formula and the results obtained by the test is shown in Figure 8. It can be seen from the figure that the error of the data calculated by the formula and the data obtained by the test is within 5%. The compressive strength prediction formula is good for calculating the compressive strength of SAP white fair-faced concrete, and the formula is only applicable to the specific material used in this study.

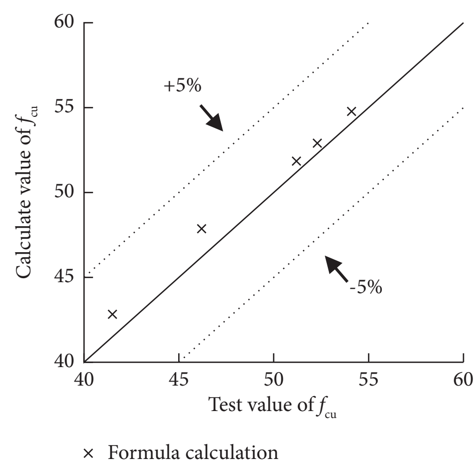


Figure 8: Comparison of test compressive strength and formula calculation results.

4.2. Prediction Formula for Tensile Splitting Strength of White Fair-Faced Concrete. The calculation formula of the tensile splitting strength of SAP white fair-faced concrete was solved by the least square method. The calculation formula is as follows:

$$f_{ts} = k_3 \cdot k_4 \cdot f_{ts}{}^{\gamma}. \tag{2}$$

Among the formula, f_{ts} are the tensile splitting strength of white fair-faced concrete mixed with SAP; $k_3 = -0.0051\lambda + 1$ is the influence coefficient of the internal curing water ratio on the tensile splitting strength; λ is the internal curing water ratio; $k_4 = -0.6921\rho + 1$ is the influence coefficient of SAP content on the tensile splitting strength of white fair-faced concrete; ρ is the SAP content, and $f_{ts}{}^{\gamma}$ is the tensile splitting strength of white fair-faced concrete.

The comparison between the tensile splitting strength of white fair-faced concrete calculated by the formula and the test results is shown in Figure 9. It can be seen from the figure that the error of the data calculated by the formula and the data obtained by the test is within 10%. The tensile

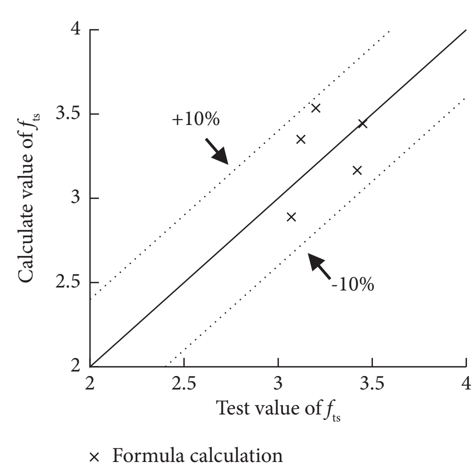


Figure 9: Comparison of test tensile splitting strength and formula calculation results.

splitting strength prediction formula is a good predictor of tensile splitting strength and is only applicable to the specific material used in this study.

5. Conclusions

In this paper, the effects of SAP admixture and internal curing water on the flowability, electrical flux, and mechanical properties of white fair-faced concrete are investigated, and the working mechanism is explained based on the SEM test results. The main conclusions are as follows:

(1) The slump of white fair-faced concrete is lower than that of ordinary fair-faced concrete. Adding SAP can effectively improve the slump of white fair-faced concrete, and it will increase with the increase of the content of SAP and the amount of internal curing water.

(2) The electrical flux of white fair-faced concrete is higher than that of ordinary fair-faced concrete. SAP has the effect of refining the pore structure, which can effectively improve the durability of white fair-faced concrete. When the SAP dosage is 0.3%, the electrical flux decreases the most. With the same SAP content, the electric flux decreases with the increase of the internal curing water, and adding SAP in the white fair-faced concrete can effectively exert its internal curing effect.

(3) SAP shrinks after releasing water, resulting in the increase of internal porosity, which will deteriorate the compressive strength and tensile splitting strength of white fair-faced concrete, especially the compressive strength. It is necessary to focus on the significant drop in the compressive strength of white fair-faced concrete caused by the addition of SAP. Adding 0.3% SAP can significantly improve the tensile-compression ratio, which is conducive to enhancing the tensile strength and preventing cracks on the premise of meeting the compressive strength requirement.

(4) The incorporation of SAP can effectively refine the internal pore structure of white fair-faced concrete, promote the secondary hydration of fly ash, and facilitate the internal structure of white fair-faced concrete to be dense.

(5) Considering flowability, durability performance, and mechanical performance, the SAP content of 0.3% and the internal curing water ratio of 10 can achieve the optimal performance of white fair-faced concrete.

(6) Based on the test data, the prediction formulas for compressive strength and tensile splitting strength of white fair-faced concrete mixed with SAP applicable to this study using specific materials were presented. The calculation results of the formula are in good agreement with the test data.

Data Availability

Data are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Z.J.P. conceptualized the study; Z.J.P., S.J., and W.Z.B. performed the methodology; C.R. and Z.T.R. performed formal analysis; Y.C.Z, Z.T.R., and C.R. performed investigation; Z.J.P. and L.H.X. wrote the original draft; Z.J.P., S.J., and W.Z.B. wrote, reviewed, and edited the article. All the authors have read and agreed to the published version of the manuscript.

Acknowledgments

This work was financially supported by the National Natural Science Foundation of China (51678152), Fujian Province Residential Construction Industry Construction Technology Research and Development Project (2022-K-29), and the Natural Science Foundation Project of Fujian Province (2021J011063).

References

[1] X. C. Han, Y. Pan, Y. D. Xie, X. Zhang, Z. X. Hao, and C. X. Qian, "Research on appraisal of fair-faced concrete appearance quality by UAV image acquisition method," *Materials Reports*, vol. 35, pp. 205–212, 2021.

[2] K. P. Gu, F. Yu, S. J. Ye et al., "Effect of admixture on appearance of high durable fair-faced concrete," *Port and Waterway Engineering*, vol. 10, pp. 63–67, 2018.

[3] Y. P. Tao, K. P. Gu, and S. Zhong, "The effect of fly ash on the durability of fair-faced concrete under seawater erosion environment," *New Building Materials*, vol. 45, no. 5, pp. 14–17+40, 2018.

[4] C. Dow and F. P. Glasser, "Calcium carbonate efflorescence on Portland cement and building materials," *Cement and Concrete Research*, vol. 33, no. 1, pp. 147–154, 2003.

[5] Y. L. Wu, W. Liu, S. N. Liu, K. P. Gu, and J. T. Zhang, "Research on optimum preparation of white fair-faced concrete for main structure of Taihu tunnel," *New Building Materials*, vol. 48, no. 6, pp. 46–50+110, 2021.

[6] D. Yang, J. Kim, Y. X. Zhou, W. Wang, and Q. F. Guan, "Emerging role of transient receptor potential (TRP) channels in cancer progression," *BMB reports*, vol. 53, no. 3, pp. 125–132, 2020.

[7] D. Yang, I. Deschênes, J. D. Fu, Y. X. Zhou, W. Wang, and Q. F. Guan, "Multilayer control of cardiac electrophysiology by microRNAs," *Journal of Molecular and Cellular Cardiology*, vol. 166, no. 10, pp. 107–115, 2022.

[8] G. Espinoza-Hijazin, Á. Paul, and M. Lopez, "Concrete containing natural pozzolans: new challenges for internal curing," *Journal of Materials in Civil Engineering*, vol. 24, no. 8, pp. 981–988, 2012.

[9] B. Craeye, M. Geirnaert, and G. D. Schutter, "Super absorbing polymers as an internal curing agent for mitigation of early-age cracking of high-performance concrete bridge decks," *Construction and Building Materials*, vol. 25, no. 1, pp. 1–13, 2011.

[10] A. Bentur, S. Igarashi, and K. Kovler, "Prevention of autogenous shrinkage in high-strength concrete by internal curing using wet lightweight aggregates," *Cement and Concrete Research*, vol. 31, no. 11, pp. 1587–1591, 2001.

[11] A. S. El-Dieb and R. D. Hooton, "Water-permeability measurement of high-performance concrete using a high-pressure triaxial cell," *Cement and Concrete Research*, vol. 25, no. 6, pp. 1199–1208, 1995.

[12] M. I. Khan and C. J. Lynsdale, "Strength, permeability, and carbonation of high-performance concrete," *Cement and Concrete Research*, vol. 32, no. 1, pp. 123–131, 2002.

[13] Y. D. Han, J. Zhang, Y. M. Luosun, and T. Y. Hao, "Effect of internal curing on internal relative humidity and shrinkage of high strength concrete slabs," *Construction and Building Materials*, vol. 61, pp. 41–49, 2014.

[14] L. C. Wang and L. Zhang, "Research progress on concrete internal curing technology," *Journal of Building Materials*, vol. 23, no. 6, pp. 1471–1478, 2020.

[15] A. Pourjavadi, S. M. Fakoorpoor, A. Khaloo, and P. Hosseini, "Improving the performance of cement-based composites containing superabsorbent polymers by utilization of nano-SiO2 particles," *Materials and Design*, vol. 42, pp. 94–101, 2012.

[16] S. Zhutovsky, K. Kovler, and A. Bentur, "Efficiency of lightweight aggregates for internal curing of high strength concrete to eliminate autogenous shrinkage," *Materials and Structures*, vol. 35, no. 246, pp. 97–101, 2002.

[17] R. Henkensiefken, T. E. Nantung, and W. J. Weiss, "Reducing restrained shrinkage cracking in concrete: examining the behavior of self-curing concrete made using different volumes of saturated lightweight aggregate," in *Proceedings of the 2008 Concrete Bridge Conference Federal Highway Administration National Concrete Bridge Council Missouri Department of Transportation American Concrete Institute (ACI)*, St Louis, MO, USA, January, 2008.

[18] A. Radlinska, F. Rajabipour, B. Bucher, R. Henkensiefken, G. Sant, and J. Weiss, "Shrinkage mitigation strategies in cementitious systems: a closer look at differences in sealed and unsealed behavior," *Transportation Research Record*, vol. 2070, no. 1, pp. 59–67, 2008.

[19] K. Kovler and O. M. Jensen, "Internal curing of concrete, state-of-the-art report of RILEM technical committee 196-ICC," *Rilem Report*, vol. 41, 2007.

[20] P. Lura, M. Wyrzykowski, C. Tang, and E. Lehmann, "Internal curing with lightweight aggregate produced from biomass-derived waste," *Cement and Concrete Research*, vol. 59, pp. 24–33, 2014.

[21] H. Y. Xia, G. T. Zhang, X. Zhao, G. Y. Liu, L. F. Song, and H. X. Chen, "Super-absorbent polymer for concrete internal curing agent and its latest research progress," *Concrete*, vol. 12, pp. 85–89, 2020.

[22] K. F. Tan and X. C. Pu, "Strength and durability of high strength light weight concrete under elevated curing conditions," *Journal of Southwest University of Science and Technology*, vol. 24, no. 2, pp. 27–31, 2009.

[23] F. Z. Wang, W. X. Wu, Y. F. Zhou, J. Wang, and W. Yang, "Comparison of the internal curing effect of the pre-wetted lightweight aggregate and super-absorbent polymer," *Journal of Wuhan University of Technology*, vol. 32, no. 14, pp. 21–25, 2010.

[24] A. Paul and M. Lopez, "Assessing lightweight aggregate efficiency for maximizing internal curing performance," *ACI Materials Journal*, vol. 108, no. 4, pp. 385–394, 2011.

[25] M. Wyrzykowski, P. Lura, F. Pesavento, and D. Gawin, "Modeling of water migration during internal curing with superabsorbent polymers," *Journal of Materials in Civil Engineering*, vol. 24, no. 8, pp. 1006–1016, 2012.

[26] P. Lura, F. Durand, and A. Loukili, "Compressive strength of cement pastes and mortars with superabsorbent polymers," in *Proceedings of the International RILEM Conference on Volume Changes of Hardening Concrete: Testing and Mitigation*, pp. 117–125, Rilem Publications SARL, Lyngby, Denmark, January, 2006.

[27] Mechtcherine, *Application of Superabsorbent Polymers (SAP) in concrete Constructions*, Springer, Netherlands, 2012.

[28] D. Shen, T. Wang, Y. Chen, M. Wang, and G. Jiang, "Effect of internal curing with superabsorbent polymers on the relative humidity of early-age concrete," *Construction and Building Materials*, vol. 99, pp. 246–253, 2015.

[29] S. Igarashi and A. Watanabe, "Experimental study on prevention of autogenous deformation by internal curing using super-absorbent polymer particles," in *Proceedings of the International RILEM conference on volume changes of hardening concrete: testing and mitigation*, vol. 100, pp. 77–86, RILEM Publications SARL, Paris, France, January, 2006.

[30] M. T. Hasholt, O. M. Jensen, K. Kovler, and S. Zhutovsky, "Can superabsorbent polymers mitigate autogenous shrinkage of internally cured concrete without compromising the strength?" *Construction and Building Materials*, vol. 31, pp. 226–230, 2012.

[31] X. M. Kong and Z. L. Zhang, "Investigation on the shrinkage -reducing effect of superabsorbent polymer in high-strength concrete and its mechanism," *Journal of Building Materials*, vol. 4, pp. 559–565, 2014.

[32] Y. D. Jiang, Z. Q. Jin, Y. F. Chen, and J. F. Fan, "Effect of super-absorbent polymer on hydration and compressive strength of concrete," *Materials Reports*, vol. 31, no. 24, pp. 40–44+49, 2017.

[33] O. M. Jensen and G. Bentz, "On the mitigation of early age cracking," in *Proceedings of the Third International Research Seminar on Self-Desiccation and Its Importance in Concrete Technology*, pp. 195–203, Gaithersburg, ML, USA, June, 2002.

[34] Q. H. Sun, Y. Q. Wei, Y. F. Meng, and Q. Ma, "Study on impermeability of super absorption polymer concrete," *New Building Materials*, vol. 36, no. 6, pp. 68–71, 2009.

[35] C. Ouattara Coumoin, F. Wang, J. Yang, and Z. Liu, "Effect of SAP on properties of high-performance concrete under marine wetting and drying cycles," *Journal of Wuhan University of Technology-Materials Science Edition*, vol. 34, no. 5, pp. 1136–1142, 2019.

[36] S. E. Chidiac, S. Mihaljevic, S. A. Krachkovskiy, and G. R. Goward, "Efficiency measure of SAP as internal curing for cement using NMR & MRI," *Construction and Building Materials*, vol. 278, no. 5, Article ID 122365, 2021.

[37] B. J. Olawuyi and W. P. Boshoff, "Influence of SAP content and curing age on air void distribution of high-performance concrete using 3D volume analysis," *Construction and Building Materials*, vol. 135, no. 15, pp. 580–589, 2017.

[38] D. Shen, C. Liu, C. Li, X. Zhao, and G. Jiang, "Influence of Barchip fiber length on early-age behavior and cracking resistance of concrete internally cured with superabsorbent

polymers," *Construction and Building Materials*, vol. 214, pp. 219–231, 2019.

[39] F. R. Karim, "Influence of internal curing on the properties of non-fibrous high strength concrete-a critical review," *Journal of Cement Based Composites*, vol. 3, pp. 1–6, 2021.

[40] T. C. Powers, "Mechanisms of shrinkage and reversible creep of hardening cement paste structure of concrete and its behavior under load," *London: Cement and Concrete Associanon*, vol. 5, pp. 319–344, 1965.

[41] O. M. Jensen and P. F. Hansen, "Water-entrained cement-based materials," *Cement and Concrete Research*, vol. 31, no. 4, pp. 647–654, 2001.

[42] J. Dang, J. Zhao, and Z. Du, "Effect of superabsorbent polymer on the properties of concrete," *Polymers*, vol. 9, no. 12, p. 672, 2017.

[43] National standard of the people's Republic of China, *Standard for Performance Test Methods of Ordinary concrete Mixtures: GB/T50080-2016*, China Construction Industry Press, Beijing, China, 2016.

[44] National standard of the people's Republic of China, *Standard for Test Methods for Long-Term Performance and Durability of Ordinary concrete: GBT50082-2009*, China Construction Industry Press, Beijing, China, 2009.

[45] National Standard of the People's Republic of China, *Standard for Test Methods of Mechanical Properties of Ordinary concrete: GB/T50081-2002*, China Construction Industry Press, Beijing, China, 2002.

[46] B. Sun, H. Wu, W. Song, Z. Li, and J. Yu, "Design methodology and mechanical properties of Superabsorbent Polymer (SAP) cement-based materials," *Construction and Building Materials*, vol. 204, pp. 440–449, 2019.

[47] S. H. Kang, S. G. Hong, and J. Moon, "Importance of monovalent ions on water retention capacity of superabsorbent polymer in cement-based solutions," *Cement and Concrete Composites*, vol. 88, pp. 64–72, 2018.

[48] X. Zheng, M. Han, and L. Liu, "Effect of superabsorbent polymer on the mechanical performance and microstructure of concrete," *Materials*, vol. 14, no. 12, p. 3232, 2021.

[49] E. M. J. Bérodier, A. C. A. Muller, and K. L. Scrivener, "Effect of sulfate on CSH at early age," *Cement and Concrete Research*, vol. 138, Article ID 106248, 2020.

[50] D. K. Fan, J. Wang, Q. Ma, and H. Y. Qu, "Research on the strength development of concrete internally cured by superabsorbent polymer and the mechanism," *Concrete*, vol. 10, pp. 129–132+137, 2021.