Performance Study of Sulfate-Resistant Admixtures on Different Brands of Cement

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Abstract. This paper primarily explores the fundamental properties of cement and its resistance to sulfate attack, focusing on the effects of incorporating a sulfate resistance agent on the basic properties of different cement brands. Additionally, it investigates the alterations in sulfate attack resistance induced by the introduction of the anti-sulfate agent. Based on experimental results, the study aims to assess the applicability of the chosen sulfate resistance agent across diverse cement brands.Furthermore, utilizing scanning electron microscopy (SEM), the research delves into the microscopic changes in the hydration structure of cement after the addition of the sulfate resistance agent. This in-depth analysis seeks to elucidate the reasons behind the enhancement of sulfate attack resistance in cement with the incorporation of the anti-sulfate agent. The objective is to evaluate the practical performance of this product under various cement brand conditions and validate its performance at the microscopic level, providing a fundamental theoretical framework for the practical engineering application of this product.The experimental results indicate the superior performance and strong universality of the sulfate resistance agent (Point-KS).

Keywords: Cement ; Sulfate ; Corrosion ; Admixture ; Performance

1 Introduction

Sulfate attack is considered a critical environmental factor leading to a decrease in the durability and lifespan of cement materials. Its impact extends to regions with saline-alkali soils, salt lakes in western China, coastal areas, and locations near groundwater, as well as environments worldwide using concrete structures. Scholars globally have extensively studied sulfate attack on cement materials since the second half of the 20th century.

Groundbreaking studies by Mehta et al. [1], Skalny et al. [2], and Müllauer et al. [3-4] suggest that the formation of calcium aluminate sulfate is the fundamental cause of concrete expansion and damage due to sulfate attack. In-depth research by Zhang Meng et al. [5-6] on the microstructure characteristics of concrete under sulfate corrosion elucidates the effects of sulfate attack, providing a microscopic understanding of the mechanisms behind sulfate attack. Researchers such as Jiang

Q. Gao et al. (eds.), *Proceedings of the 2024 7th International Conference on Structural Engineering and Industrial Architecture (ICSEIA 2024)*, Atlantis Highlights in Engineering 30,
https://doi.org/10.2991/978-94-6463-429-7_7

Fengguo, Yu Xuefeng, and Fang Xiaowan [7-9] have conducted comprehensive studies on the durability and damage of concrete under sulfate attack. Scholars including Tian Wei, Pan Yiming, and Wu Jiangtao [10-13] have extensively researched the influencing factors, macroscopic, and microscopic mechanisms of sulfate attack on concrete. Wang Yuling and Wang Chunfu [14] provide a comprehensive review of concrete sulfate attack and strategies for sulfate resistance, offering strong technical support for engineering practices.

This study revolves around the fundamental properties of cement and performance indicators related to sulfate attack erosion. The primary objective is to investigate the effects of incorporating Point-KS, a sulfate resistance agent, on the fundamental properties and sulfate attack resistance of various cement brands. Through meticulous analysis of experimental results, this research aims to scrutinize whether distinct performance differentials exist in the efficacy of Point-KS across different cement brands. The ultimate purpose is to validate and assess the universality of Point-KS products, facilitating a fundamental reference for the practical engineering application of Point-KS in diverse contexts.

2 Materials and Methods

2.1 Raw Materials for the Experiment

Sulfate-Resistant Admixture.

The anti-sulfate erosion agent product used in this test was Point-KS (KS for short) provided by KZJ New Materials Group, and a dosage of 6% was used in this test.

Experimental Cement.

The cement varieties employed in this experimental study comprise the following: Sulfate-Resistant Cement (GK) P.O42.5R, procured from Jiuqi Building Materials Co., Ltd. in Zhucheng City; Reference Cement (JZ) P.O42.5, obtained from China National Building Materials Science Research Institute Co., Ltd.; Runfeng Cement (RF) P.O42.5R, sourced from China Resources Cement Holdings Limited; Chunchi Cement (CC) P.O42.5, acquired from Fujian Chunchi Cement Group Co., Ltd. The intricate chemical composition is delineated in Table 1 and Table 2.

Table 1. Physical performance of experimental cement

Number	Fineness /%	Standard consistency /%	Setting time /Minute		Flexural strength /MPa		Compressive strength /MPa	
			Initial	Final	3 days	28 days	3 days	28 days
GK	3.18	25.2	163	257	5.43	7.33	26.2	54.1
JZ	3.06	25.9	132	214	5.36	7.11	26.7	51.7
RF	3.90	27.2	197	283	5.51	7.06	28.8	48.9
CC	1.68	29.2	162	249	5.57	6.94	30.9	47.3

Table 2. Chemical composition of experimental cement

Number	CaO/%	SiO_2/%	Al_2O_3/%	Fe_2O_3/%	MgO/%	SO_3/%	Na_2O/%	K_2O/%	fCaO/%
GK	64.23	22.74	4.27	2.52	3.56	1.70	0.22	0.36	0.12
JZ	63.70	23.53	4.51	3.50	2.36	2.42	0.42	0.18	0.56
RF	62.48	23.42	4.19	3.01	1.08	2.26	0.38	0.32	2.10
CC	66.07	22.73	2.66	2.39	1.83	1.72	0.19	0.43	0.54

2.2 Instruments and Test Methods

Experimental Instruments.

The instruments and equipment used in this experiment are listed in Table 3.

Table 3. Experimental instruments and equipment

Number	Instrument Name	Device model	Manufacturer
1	Electronic balance	DM.3	DM.3 Flagship Store
2	Cement mortar mixer	JJ-5	Wuxi Building Materials Instrument Machinery Factory
3	Cement Sand Flow Tester	NLD-3	Wuxi Jianyi Instrument Machinery Co.
4	Cement sand vibrating table	ZH.DG-80	Wuxi Building Materials Instrument Machinery Factory
5	Cement standard consistency and setting time tester	MD-7	Wuxi Building Materials Instrument Machinery Factory
6	Cement concrete rapid curing box	ACW-85	Suzhou Donghua Testing Instrument Co.
7	Pressure testing machine	TYE-300B	Wuxi Jianyi Instrument Machinery Co.
8	Length gauge	BC-300	Hangzhou Journey Instrument Co.

Cement Performance Test Methods.

Cement compressive strength, standard consistency water requirement, and setting time were tested according to GB/T50107-2013 "Standard for Strength Inspection and Evaluation of Concrete" and GB/T1346-2011 "Methods for Testing Water Requirement, Setting Time, and Stability of Cement Standard Consistency."

Sulfate-Resistant Admixture Performance Test Methods.

The performance test methods for sulfate resistance include compressive strength ratio and expansion coefficient testing, following JC/T313-2009 "Test Method for Expansion Rate of Expansive Cement" and JC/T1011-2021 "Concrete Corrosion-resistant Anticorrosive Agent."

3 Results and Analysis

3.1 Impact Analysis of Compressive Strength Influence

To investigate the influence of incorporating sulfate-resistant admixtures on the compressive strength of different cements, the test results are shown in Figure 1.

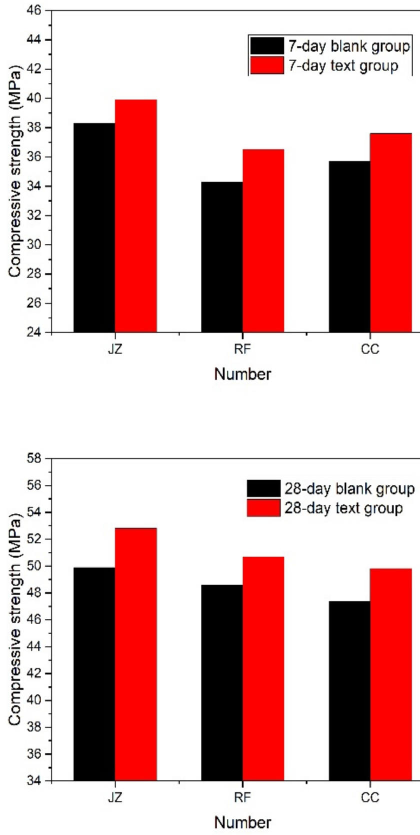
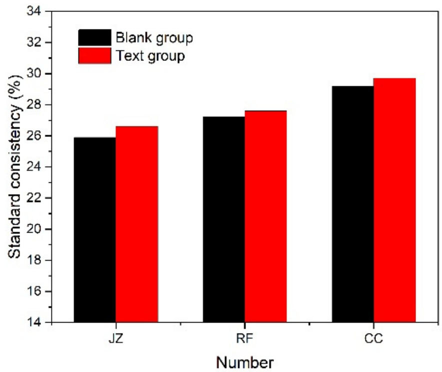


Fig. 1. Compressive strength of experimental cement at 7 days (left) and 28 days (right)

The compressive strength of cements with added KS product at 7 and 28 days is higher than that of the blank group. Further analysis reveals that the addition of the KS product increases the cement hydration rate, leading to an increase in C3S content and early strength improvement. The addition of the KS product to different brands of cement effectively promotes faster and more thorough cement hydration reactions, contributing to strength improvement. The addition of KS product to different brands of cement can significantly enhance their compressive strength, indicating good universality.

3.2 Impact Analysis of Standard Consistency and Setting Time

To explore the influence of incorporating sulfate-resistant admixtures on the standard consistency water demand and setting time of different cements, the test results are shown in Figure 2.



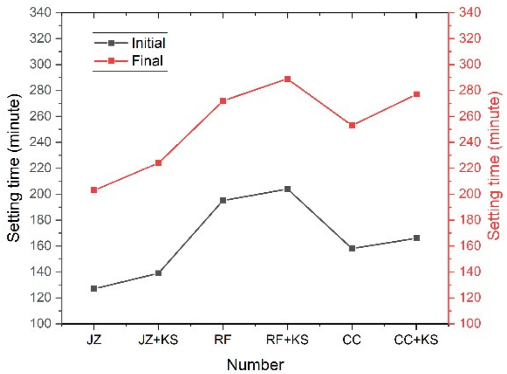


Fig. 2. Standard consistency (left) and setting time of experimental cement (right)

The KS product itself requires more water than the experimental Cement, resulting in an increased water demand. The setting time changes due to the increased water demand affecting the hydration reaction rate. Incorporating KS product increases the average standard consistency water demand by 0.53% and extends the average initial setting time by 6 minutes and final setting time by 19 minutes. Therefore, in practical applications, adjustments should be made to construction water quantities and demolding times based on these effects.

3.3 Expansion Coefficient

This study investigates the differences in the expansion coefficients of different cement brands when incorporating sulfate-resistant agents under the same erosion conditions. The results are presented in Figure 3.

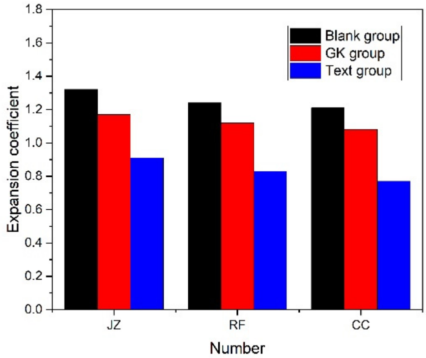


Fig. 3. Comparison of coefficients of expansion of experimental cements

It is evident from the comparison chart that the internal pore structure of specimens becomes denser after adding the KS product, resulting in a significant decrease in the expansion coefficient compared to the blank group. The expansion coefficient is even lower than that of the high-strength group, indicating the excellent performance of the KS product. The application of the KS product effectively addresses the expansion issue caused by sulfate corrosion and is superior to the direct use of GK cement under the same erosion conditions. Additionally, considering the higher cost of GK cement, using this product helps reduce engineering costs.

3.4 Corrosion Resistance Coefficient

This study investigates the differences in erosion coefficients of different cement brands when incorporating sulfate-resistant agents under the same erosion conditions. The results are presented in Table 4.

Table 4. Corrosion resistance coefficient of experimental cement

Number	90-day compressive strength /MPa		90-day corrosion resistance coefficient
	Curing in Water at 20°C	Immersion in corrosive solution	
GK	56.8	47.7	0.84
JZ	54.8	40.6	0.74
JZ+KS	52.8	49.6	0.94
RF	60.1	46.3	0.77
RF+KS	61.3	57.0	0.93
CC	52.2	39.2	0.75
CC+KS	51.4	47.3	0.92

In this experiment, a 90-day immersion in a 15% sodium sulfate erosion solution was conducted, revealing varying degrees of peeling and damage in specimens from all groups. However, specimens with the addition of the KS product exhibited a noticeable reduction in macroscopic damage. Combining practical observations and corrosion resistance coefficient analysis, specimens with the addition of the KS product retained higher strength values after 90 days of erosion, with an average increase of 0.2 in the corrosion resistance coefficient compared to the blank group and exceeding the GK group under the same conditions. This indicates that the KS product performs well in sulfate corrosion resistance, demonstrating superior performance and good universality in this aspect.

3.5 Scanning Electron Microscopy (SEM) Analysis

To delve into the influence of incorporating sulfate-resistant admixtures on the hydration structure of different cements at a microscopic level, SEM was used for testing. A comparison of the microscopic morphology between the blank and test groups is shown in Figures 4 and 5.

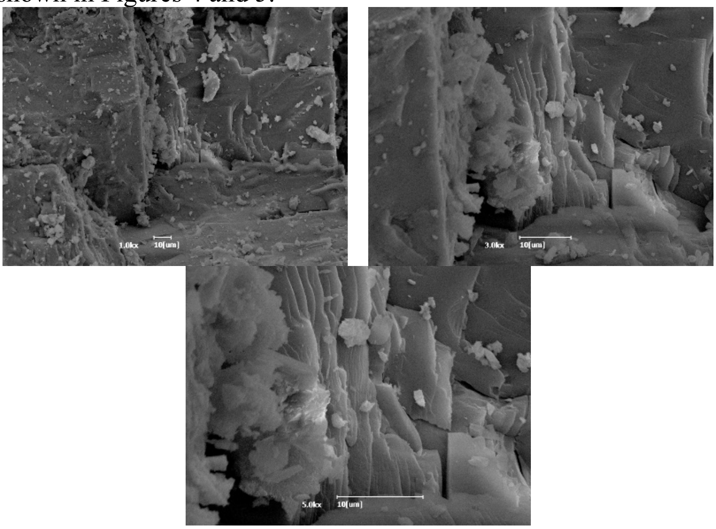
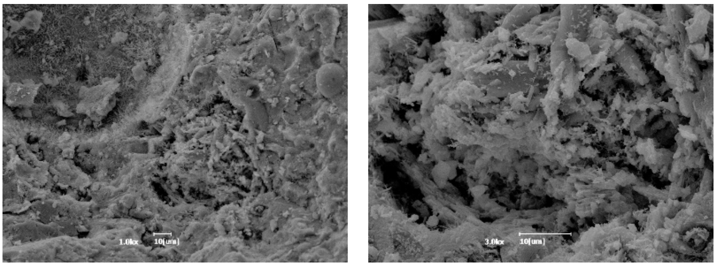


Fig. 4. SEM images of ordinary concrete at 28 days (×1000), (×3000), and (×5000)



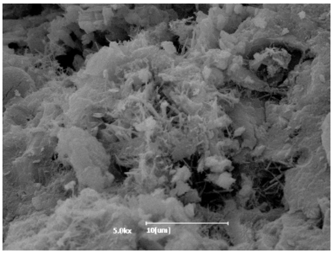


Fig. 5. SEM images of sulfate-resistant concrete with KS product addition at 28 days (×1000), (×3000), and (×5000)

By comparing SEM images of the two concretes at 28 days of age, significant differences are observed in the surface of the cementitious slurry and the transition zone between aggregates and the slurry. At ×1000 magnification, the interface of ordinary concrete exhibits a smooth lamellar structure, while the interface of sulfate-resistant concrete with the addition of KS product appears as a flocculent interwoven structure. At ×3000 magnification, the smooth lamellar structure is more pronounced, mainly consisting of hexagonal plate-shaped Ca(OH)2 crystals with relatively weak interface bonding force. In contrast, the flocculent interwoven structure is more pronounced, with numerous irregularly shaped C-S-H gel particles interwoven, and the voids are filled with needle-shaped ettringite (AFt). At ×5000 magnification, it is further clarified that the flocculent interwoven structure exhibits large clusters of particle-like calcium silicate hydrate, and the fine pores contain a large number of needle-shaped and rod-shaped aluminum ettringite (AFt), cutting off some capillary passages, resulting in a denser structure with fewer defects. In comparison, the smooth lamellar structure exhibits more defects. In summary, the SEM analysis at the microscopic level verifies the excellent sulfate corrosion resistance performance of the KS product.

4 Conclusions

This experiment, through an investigation into the impact of incorporating sulfate-resistant admixtures on different cement performance indicators, concludes as follows:

- After adding the KS product, both the 7-day and 28-day compressive strengths are higher than those of the blank group. The addition of KS product to different brands of cement effectively enhances their compressive strength, indicating good universality.
- The addition of KS product increases the average standard consistency water demand by 0.53%, extends the average initial setting time by 6 minutes, and extends the final setting time by 19 minutes. Practical usage should consider these effects and adjust construction water quantities and demolding times accordingly.

- Under the same erosion conditions, the sulfate corrosion resistance of specimens with the addition of KS product is significantly superior to the blank group and even better than sulfate-resistant cement. This demonstrates the effective sulfate corrosion resistance performance of the KS product.
- SEM testing at a microscopic level confirms that the addition of KS product optimizes the pore structure of concrete at the microscopic level, reducing micro-defects, and significantly improving the sulfate corrosion resistance of concrete.

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