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Effects of Polycarboxylate Superplasticizer on the Rheological Properties of Cement-Based Composites

Peng Zhang[1], Jingjiang Wu[1], Xiaoxue Wei[1], Chengshi Zhang[1], Zhen Gao[2*]

[1] Country China Construction Seventh Engineering Division Corp. Ltd., Transportation Construction Company, 450003 Zhengzhou, China
[2] School of Water Conservancy and Transportation, Zhengzhou University, 450001 Zhengzhou, China

[*] Correspondence: Zhen Gao (gao-zhen@zzu.edu.cn)

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Abstract: The effects of polycarboxylate superplasticizer (PCE) on the rheological properties and workability of cement-based composites were investigated by testing parameters such as static yield stress, dynamic yield stress, plastic viscosity, slump flow, bleeding rate, and penetration depth. The correlation between the dosage of PCE and the rheological parameters of fresh cement-based composites was analyzed. The results indicated that with an increase in the PCE dosage, the static yield stress, dynamic yield stress, and plastic viscosity of fresh cement-based composites decreased, demonstrating that PCE can improve the rheological properties of these composites. As the PCE dosage increased, the slump flow and bleeding rate of fresh cement-based composites also increased, but the rate of change decreased at higher dosages. Additionally, with an increase in PCE dosage, the penetration depth gradually increased, while the penetration depth difference (ΔH) decreased. Furthermore, the compressive strength of cement-based composite cubes slightly decreased with an increase in PCE dosage.

Keywords: Polycarboxylate superplasticizer (PCE); Cement-based composites; Rheological properties; Workability

1 Introduction

Cement has a long history of over two hundred years since its inception. Due to its low cost, abundant materials, simple production and calcination process, and excellent mechanical properties, it has greatly promoted the development of the era and the progress of human society. For a long time, as an important cementing material, it has been widely used in civil construction, water conservancy, national defense, and other projects [1, 2]. Currently, China is the largest cement manufacturer globally, and the cement industry is one of the pillars of China's basic raw material industries. In recent years, cement production in China has been increasing year by year. According to some data, in 2023 alone, China's cement production reached 2.02 billion tons, accounting for more than half of the world's total cement production [3, 4]. Since entering the new millennium, China has proposed the grand initiative of the "Belt and Road," which has been widely recognized worldwide. The priority area of the "Belt and Road" is interconnectivity in infrastructure. With the continuous increase in demand for infrastructure construction, cement-based composites with high strength and excellent durability have become the focus and difficulty of research [5]. However, high-performance cement-based composites often have a low water-cement ratio, resulting in poor dispersion of the mixture and easy cracking after hardening [6–8].

Concrete admixtures are the key materials to solve the above problems and the simplest method [9]. Among them, PCE is an important component of admixtures (accounting for more than 80%). It has the advantages of low dosage, high water reduction rate, cost-saving, high workability, and wide applicability. It can significantly reduce the water consumption of concrete without changing the workability of cement-based composites and significantly increase the strength of concrete, which can be used to prepare high-strength or ultra-high-strength concrete [10–12]. Boukendakdji et al. [13] studied the effects of high-performance PCE and naphthalene-based water reducers on the properties of self-compacting concrete. The results showed that concrete with high-performance PCE had higher compressive strength at all ages and better workability than concrete with naphthalene-based water reducer.

Zhang et al. [14] studied the effects of three high-performance water reducers, b-naphthalene disulfonic acid high-performance water reducer (BNS), amino sulfonate high-performance water reducer (AS), high-performance PCE, and two retarders, citric acid and sodium gluconate, on the fluidity, fluidity loss over time, and compressive strength of sulphoaluminate cement. The results showed that the competitive adsorption effect between the retarder citric acid and the water reducers BNS and AS resulted in lower initial fluidity of cement paste. However, there was no competition between the retarder sodium gluconate and the water reducers BNS and AS, and the combined use of the two retarders and high-performance PCE was more beneficial for cement strength, fluidity, and fluidity loss. Wang et al. [15] studied the effect of PCEs on the resistance to chloride ion penetration and sulfate attack of concrete. The results indicated that PCE (M400C3.5, nEO = 9) with the shortest side chain has the best effect on improving the resistance to chloride ion penetration and sulfate attack of concrete. Cheah et al. [12] explored the effects of the types and combinations of PCEs with different chemical structures on the performance of high-performance self-consolidated concrete (HPSCC). The use of mixed methoxy polyethylene glycol and isoprenyl polyethylene glycol PCEs had an adverse effect on the mechanical properties and drying shrinkage of HPSCC. This is due to the formation of foil and fibrous C-S-H bonds in the microstructure of concrete by PCE, which weakens the strength of the C-S-H network. In summary, PCE can effectively reduce cement consumption and carbon dioxide emissions. It is also the most effective, simple, and economical key technical approach to achieving workability control and mechanical performance enhancement of cement-based composites.

Based on this, this paper proposes using cement, fly ash, and quartz sand as raw materials to study the effects of PCE on the rheological and mechanical properties of cement-based composites and to reveal the improvement law of cement-based composite properties with varying water reducer dosages. The expected results of this study can effectively alleviate the contradiction between the workability and strength of cement-based composites to meet more practical engineering needs.

2 Experimental Overview

2.1 Experimental Materials

The cementitious materials used in this experiment are P·O 42.5 ordinary Portland cement and Grade I fly ash. The specific indices are shown in Tables 1 and 2. The fine aggregate used has a particle size range of 75-120 μm, and all indicators meet the experimental requirements; the specific indices are shown in Table 3. The PCE, which is light yellow in color, was used with a water reduction rate of 28%, air content of 4.0%, and a bleeding rate ratio of 30%. The appearance is shown in Figure 1, and the specific indices are provided in Table 4.

Table 1. Main physical-mechanical properties of cement

Item	Specific Surface Area	Density	Setting Time(min)		Compressive Strength (MPa)		Flexural Strength (MPa)	
	(m^2/kg)	(g/cm^3)	Initial	Final	(3d)	(28d)	(3d)	(28d)
Value	386	3.16	90	300	26.6	54.5	5.42	8.74

Table 2. Physical parameters of fly ash

Detection Item	Water Absorption (%)	Bulk Density (g/cm^3)	Standard Consistency (%)	Density (g/cm^3)
Range	$87 \sim 128$	$0.541 \sim 1.282$	$26.4 \sim 65.8$	$1.95 \sim 2.87$
Average	105	0.77	47.1	2.16

Table 3. Physical parameters of quartz sand

Detection Item	Mohs Hardness	Specific Gravity	Wear Rate	Porosity	Crushing Rate
	(mg/l)	(g/cm^3)	(%)	(%)	(%)
Detection Result	7.5	2.66	< 0.3	> 43	6.6

Table 4. Main index of water reducing agent

Detection Item	Bleeding Rate Ratio (%)	Air Content (%)	Compressive Strength Ratio (%)	Shrinkage Ratio (%)	Water Reduction Rate (%)
Detection Result	30	4	147	98	28

Figure 1. PCE

2.2 Experimental Mix Proportions

This study mainly investigates the influence and mechanism of PCE on cement-based composites. Therefore, a controlled variable method is adopted in the experiment, with only the dosage of PCE being changed. In this experiment, the water-to-binder ratio (the ratio of the mass of added water to cementitious material) of the reference group is 0.35, and the sand-to-binder ratio is 2. Fly ash replaces 35% of the mass of Portland cement on an equal mass basis. The dosages of PCE are 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1.0%. The specific mix proportions of the cement-based composites are shown in Table 5.

Table 5. Mix proportion of cement-based composites

Test Item No.	Water	Cement	Quartz Sand	Fly Ash	Superplasticizer
	kg/m^3	kg/m^3	kg/m^3	kg/m^3	%
M-0	350	650	500	350	0
M-0.2	350	650	500	350	0.2
M-0.4	350	650	500	350	0.4
M-0.6	350	650	500	350	0.6
M-0.8	350	650	500	350	0.8
M-1.0	350	650	500	350	1

Note: M-0.4 represents a superplasticizer dosage of 0.4%

2.3 Preparation and Testing Methods for Cement-Based Composites

2.3.1 Preparation method

This study investigates the influence of PCE on the rheological, workability, and mechanical properties of cement-based composites through various tests, including rheological tests for fresh cement-based composites, lubrication layer viscosity tests, slump flow tests, bleeding rate tests, consistency tests, and compressive strength tests of cubic specimens.

The specific mixing steps for cement-based composites are as follows: First, pour quartz sand, cement, and fly ash into the mixer and mix for 2 minutes to ensure the dry material mixture is uniform. Next, mix the PCE with water and stir evenly before pouring it into the mixture. Continue mixing for another 2 minutes to form the cement-based mortar mixture. After preparing the cement-based composites, a portion of the fresh mix was placed into a rheometer bucket, consistency tester, and slump cone for testing. Another portion was placed in a bleeding rate bucket, transferred to a vibration table, vibrated for 20 seconds, and weighed before moving the bucket indoors for the bleeding test. The remaining cement-based composite was placed in a three-gang mold with dimensions of 70.7mm×70.7mm×70.7mm and vibrated on the vibration table for forming. After forming, the specimen was moved indoors and covered with a plastic film on the surface. After 24 hours, the mold was removed, and the specimen was placed in a standard curing room (temperature 20 ± 2℃, relative humidity $\geq 95\%$). The cubic compressive strength test was conducted after a curing period of 28 days.

2.3.2 Testing methods

(1) Rheological test

The rheological tests in this study were conducted using the TR-CRI automatic concrete rheometer produced by Shanghai Tongrui Instrument Equipment Co., Ltd. The specific test methods are as follows:

a) Fill the test bucket with an inner diameter of 300 mm and a height of 310 mm with 2/3 volume of fresh cement-based composites, install the cruciform rotor, and control the rise of the test bucket until it immerses the rotor to a depth of 150 mm. Measure the torque at a rotational speed of 0.1 rps (revolutions per second) to calculate the static yield stress.

b) After completing the static test, maintain the immersion depth of the cruciform rotor and sequentially measure the torque generated at rotational speeds of 0.6, 0.55, 0.5, 0.45, 0.4, 0.35, 0.3, 0.25, 0.2, and 0.15 rps to calculate the dynamic yield stress and plastic viscosity of the fresh cement-based composites. Due to the complexity of impeller rotation, the measured torque and impeller speed are used to calculate shear stress and shear rate, as shown in Eq. (1).

$$T = G + H + N \tag{1}$$

where, T is the torque, in Newton-meter (N·m); G is the y-intercept of the linear segment of the curve; H is the slope of the linear segment of the curve; N is the impeller speed, in rps.

c) Replace the cruciform rotor with a cylindrical rotor (φ 200×200 mm), control the rise of the test bucket until it immerses the cylindrical rotor to a depth of 150 mm, and sequentially measure the torque generated at rotational speeds of 0.6, 0.55, 0.5, 0.45, 0.4, 0.35, 0.3, 0.25, 0.2, and 0.15 rps to calculate the viscosity of the lubrication layer of pumpable cement-based composites [16].

The rheological test device for fresh cement-based composites and the lubrication layer rheological test device are shown in Figures 2 and 3, respectively. The difference between them lies in the rotors: the cruciform rotor is used for the rheological test of the mixture, and the cylindrical rotor is used for the lubrication layer rheological test.

Figure 2. Field diagram of rheological test of fresh cement-based composites

Figure 3. Field diagram of rheological test of fresh cement-based composites lubrication layer

(2) Slump flow test

The standard slump cone used in this test has a top diameter of 100 mm, a bottom diameter of 200 mm, and a height of 300 mm, as shown in Figure 4. The specific test procedure is as follows:

a) Before the test, clean the baseplate and the slump cone, ensuring that the inner wall of the cone and the baseplate are wet but free of standing water. Then, place the iron baseplate flat on the ground, position the slump cone on top of it, and secure it with both feet.

b) Fill the slump cone with the freshly mixed cement-based composite in three layers, ensuring each layer is approximately equal in volume. Tamp each layer 25 times with a tamping rod in a spiral pattern from the inside out, inserting to the bottom plate for the bottom layer and 2-3 cm into the previous layer for the middle and upper layers.

c) After tamping, scrape off the excess cement-based composite, smooth the surface, and remove any mortar that seeped out around the base of the slump cone. Lift the slump cone vertically and smoothly within 5-10 seconds, allowing the cement-based composite to flow freely onto the baseplate.

d) Once the mixture has stopped flowing, use a tape measure to measure the diameters in two perpendicular directions and take the average value as the slump flow measurement result.

Figure 4. Slump extension test diagram

(3) Bleeding rate test

The bleeding test was conducted using a bleeding bucket, a rubber bulb pipette, and a 100 ml graduated cylinder with a stopper. First, a damp cloth was used to moisten a 5 L lidded container (diameter 185 mm, height 200 mm, as shown in Figure 5). The freshly mixed cement-based composite was loaded into the bleeding bucket and placed on a vibration table for 20 seconds. Then, gently smooth the surface with a spatula, cover it with a lid to prevent evaporation, and ensure that the sample surface is about 20 mm below the rim of the bucket. Start timing from the surface smoothing. For the first 60 minutes, the bleed water was extracted every 10 minutes using a rubber bulb pipette; after that, extraction was performed every 20 minutes until there's no bleed water for three consecutive times. Before each extraction, tilt the bucket by placing a 35 mm high spacer under one side of the bottom for about 5 minutes to facilitate water extraction. After extraction, gently place the bucket flat and cover it. Each time water was extracted, it's poured into the graduated cylinder with a stopper, and the total bleed water was calculated to an accuracy of 0.01 mL/mm^2. The bleeding amount is the average of three samples; if the difference between the middle value and the other values exceeds 15%, the middle value is taken as the test result. If the difference between the highest and lowest values and the middle value exceeds 15% of the middle value, the test is invalid [17]. The calculation of the bleeding rate is shown in Eq. (2):

$$B = \frac{w_b}{(w_1/G)/G_1} \times 100 \tag{2}$$

where, B is the bleeding rate; w_b is the total mass of bleed water, in grams (g); w_1 is the amount of water used in the mixture, in grams (g); G is the total mass of the mixture, in grams (g); G_1 is the sample mass, in grams (g).

(4) Consistency test

This test was conducted using the SC145 digital consistency tester produced by Cangzhou Luchen Highway Instrument Co., Ltd., with a measurement accuracy of 0.01 mm. The specific test procedure is as follows:

a) Load the freshly mixed cement-based composite into the conical container of the consistency tester, tamp it, and smooth the surface. Adjust the cone frame so that the tip of the standard cone touches the surface of the fresh cement-based composite, fix the standard cone, and reset the electronic counter to zero.

Figure 5. Test diagram of bleeding rate of fresh cement-based composite

b) Release the screw to allow the standard cone to freely fall into the fresh cement-based composite.

c) Once the standard cone stops sinking, fix the screw and read the penetration depth H_1.

d) Reset the consistency tester, tamp the cement-based composite in the conical container with a steel rod, smooth it, and let it stand for ten minutes.

e) Repeat the above steps to measure the penetration depth H_2 of the fresh cement-based composite.

f) Reset the consistency tester again, tamp the cement-based composite in the conical container with a steel rod, smooth it, and measure the penetration depth H_3.

g) Calculate the penetration depth difference $\Delta H = H_3 - H_2$. The penetration depth difference ΔH can characterize the thixotropy of the fresh cement-based composite.

The on-site photo of the consistency test is shown in Figure 6.

Figure 6. On-site photo of consistency test of fresh cement-based composites

(5) Cubic compressive strength test

According to the material quantities for the cement-based composites, three 70.7mm×70.7mm×70.7mm cubic specimens were cast for each mix proportion. After 1 day of curing at room temperature, the molds were removed, and the specimens were placed in a standard curing room. After 28 days of curing, the specimens were taken out, the surface was wiped clean, dimensions were measured, the appearance was checked, and the cubic compressive strength test was conducted. The average of the three sets of data was taken as the cubic compressive strength value of the cement-based composites. The cubic compressive strength test was conducted using a 2000 kN computer-controlled servo universal testing machine produced by Shanghai Hualong Company. The loading rate was kept constant at 1.5 kN/s, and the load at failure was recorded. The cubic compressive strength of the cement-based composites is calculated according to Eq. (3):

$$f_{m,cu} = \frac{N_u}{A} \tag{3}$$

where, $f_{m,cu}$ is the cubic compressive strength, in megapascals (MPa); N_u is the failure load, in newtons (N); A is the cross-sectional area of the specimen under compression, in square millimeters (mm^2).

The compressive strength of the mortar cube is accurate to 0.1 MPa.

3 Experimental Results and Analysis

3.1 Rheological Properties of Fresh Cement-Based Composites

3.1.1 Effect of PCE on the rheological properties of fresh cement-based composites

The effect of different dosages of PCE on the rheological properties of fresh cement-based composites is shown in Figure 7. As can be seen from the figure, with the increase of PCE dosage from 0% to 1.0%, the static yield stress, dynamic yield stress, and plastic viscosity of fresh cement-based composites show a gradually decreasing trend.

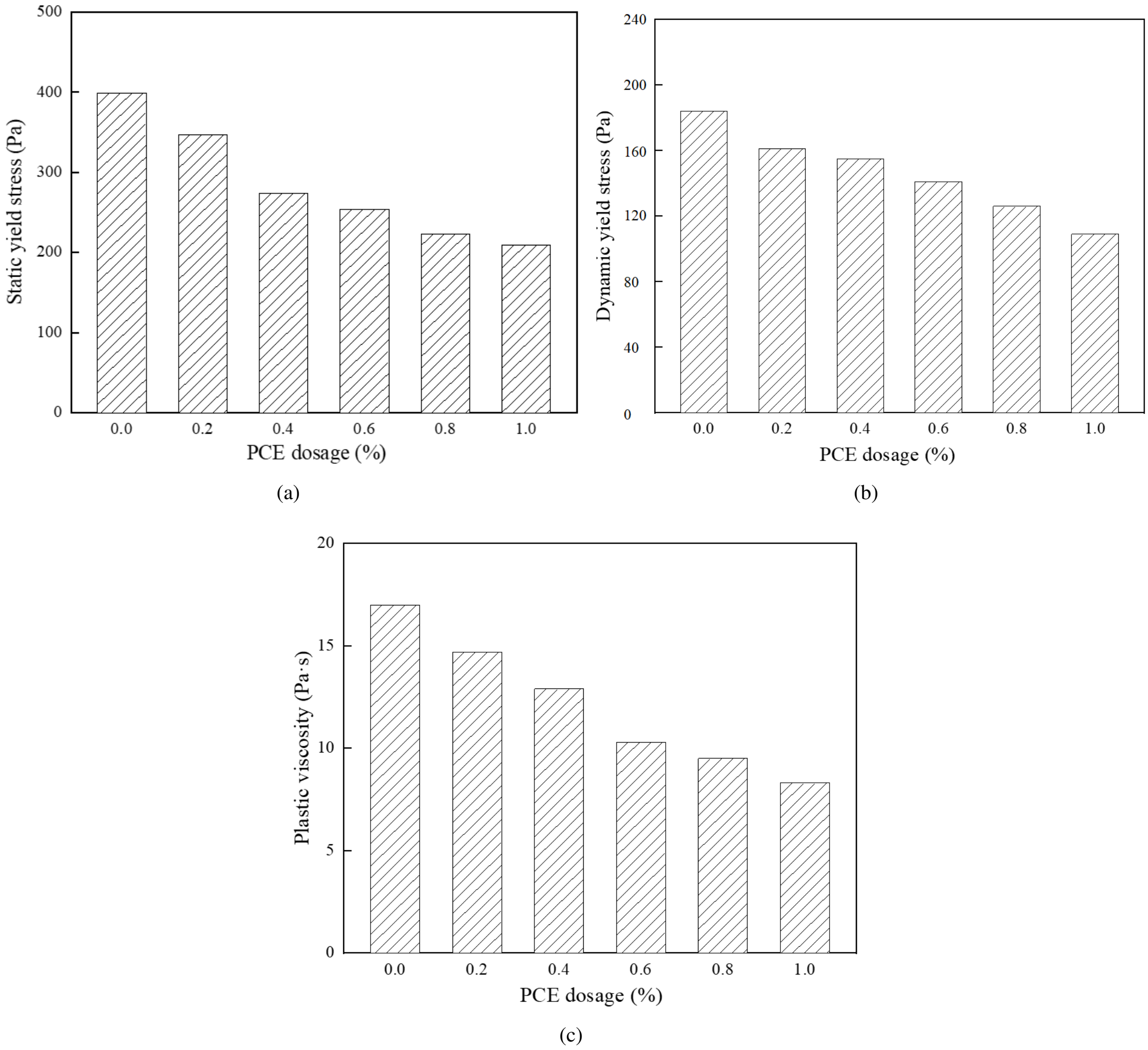


Figure 7. Effects of PCE dosages on rheological properties of fresh cement-based composites (a) Static yield stress (b) Dynamic yield stress (c) Plastic viscosity

When no PCE is added, the static yield stress, dynamic yield stress, and plastic viscosity of fresh cement-based composites are 399 Pa, 184 Pa, and 17 Pa·s, respectively. With the gradual increase of PCE dosage, the static yield stress, dynamic yield stress, and plastic viscosity of fresh cement-based composites gradually decrease, reaching a minimum when the dosage is 1.0%, at 209.34 Pa, 109 Pa, and 8.3 Pa·s, respectively. These values decreased by 190 Pa, 75 Pa, and 8.7 Pa·s, corresponding to reductions of 47.62%, 40.76%, and 48.82%.

In summary, PCE improves the rheological properties of fresh cement-based composites because it contains both hydrophobic and hydrophilic groups. The hydrophobic groups adsorb on the surface of cement particles, giving them the same charge, while the hydrophilic groups point toward the aqueous solution, forming a stable suspension system of water-cementitious material in the mixed system. Additionally, PCE can disintegrate flocculated structures in fresh cement-based composites, releasing a large amount of mixing water and thus achieving the purpose of water reduction. Therefore, the rheological properties of fresh cement-based composites are improved, with reduced static yield stress, dynamic yield stress, and plastic viscosity [18, 19].

3.1.2 Effect of PCE on the rheological properties of the lubrication layer of fresh cement paste

The effect of different dosages of PCE on the rheological properties of the lubrication layer of fresh cement-based composites is shown in Figure 8. As seen in Figure 8, with the increase in PCE dosage, the yield stress and viscosity of the lubrication layer of fresh cement-based composites show a gradually decreasing trend. When no water reducer is added, the yield stress and viscosity of the lubrication layer of fresh cement-based composites are 122 Pa and 0.071 Pa·s/m, respectively. With the increase in PCE dosage, the yield stress and viscosity of the lubrication layer gradually decrease, reaching a minimum at a dosage of 1.0%, with values of 80 Pa and 0.052 Pa·s/m, representing reductions of 34.42% and 26.76%, respectively.

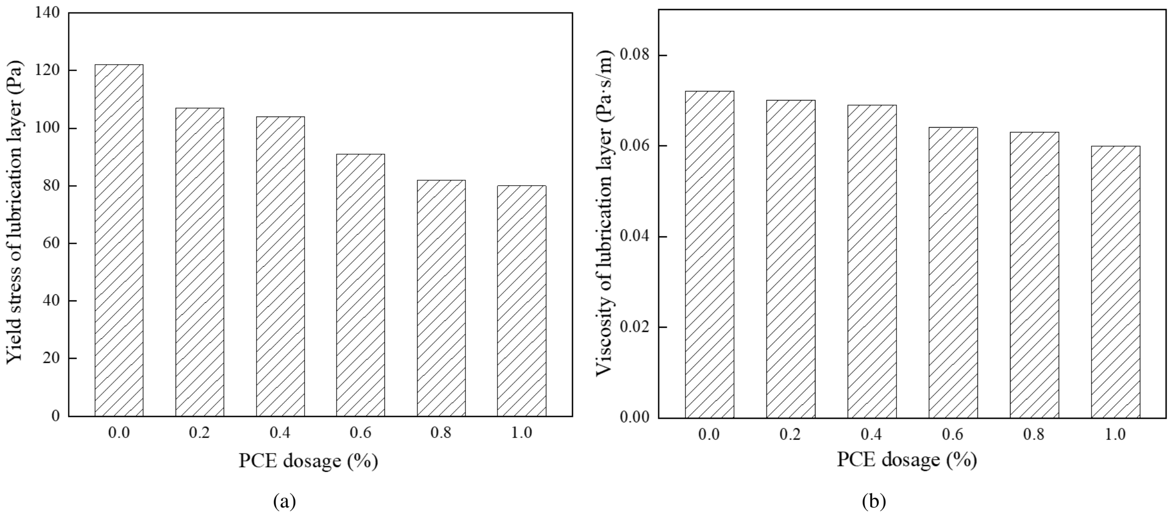


Figure 8. Effects of PCE dosage on rheological properties of lubrication layer (a) Yield stress of lubrication layer (b) Viscosity of lubrication layer

3.1.3 Correlation analysis between PCE dosage and rheological parameters of fresh cement-based composites

Based on the experimental results of the rheological properties of fresh cement-based composites measured in this study, the static yield stress, dynamic yield stress, plastic viscosity, lubrication layer yield stress, and lubrication layer viscosity of fresh cement-based composites were fitted against the PCE dosage using origin software. The fitting results are shown in Figure 9, where the vertical axis represents the rheological parameters of fresh cement-based composites, the horizontal axis represents the PCE dosage, and R^2 represents the correlation coefficient.

The quantitative relationship between the static yield stress of fresh cement-based composites and PCE dosage is shown in Eq. (4).

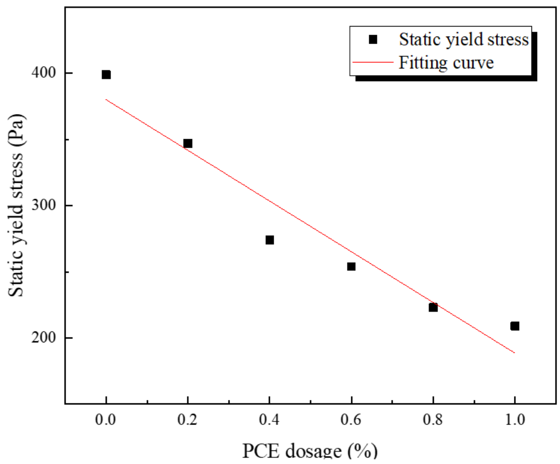
$$f_s = 380.19 - 191.7\alpha, R^2 = 0.934 \tag{4}$$

The quantitative relationship between the dynamic yield stress of fresh cement-based composites and PCE dosage is shown in Eq. (5).

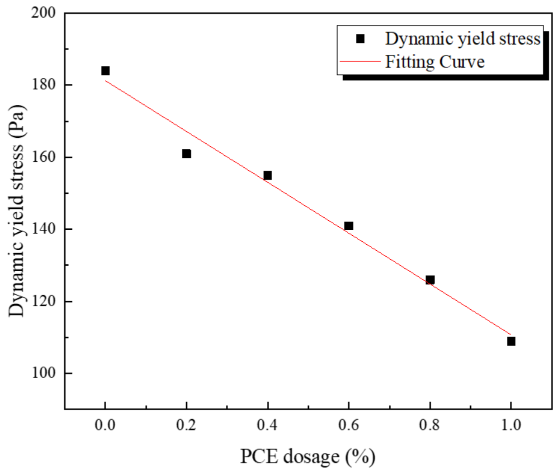
$$f_d = 181.29 - 70.57\alpha, R^2 = 0.983 \tag{5}$$

The quantitative relationship between the plastic viscosity of fresh cement-based composites and PCE dosage is shown in Eq. (6).

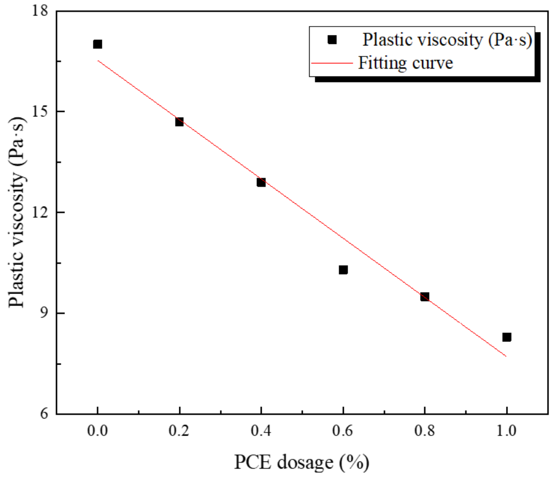
$$f_\eta = 16.52 - 8.81\alpha, R^2 = 0.973 \tag{6}$$



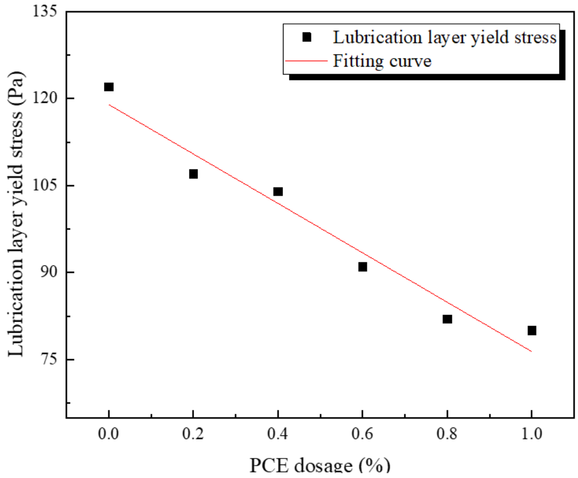
(a)



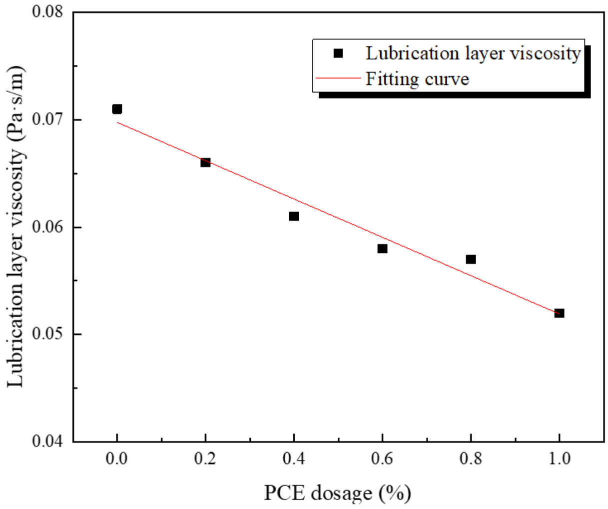
(b)



(c)



(d)



(e)

Figure 9. Correlation between PCE dosage and rheological parameters of fresh cement-based composites (a) Fitting curve between PCE dosage and static yield stress (b) Fitting curve between PCE dosage and dynamic yield stress (c) Fitting curve between PCE dosage and plastic viscosity (d) Fitting curve between PCE dosage and lubrication layer yield stress (e) Fitting curve between PCE dosage and lubrication layer viscosity

The quantitative relationship between the yield stress of the lubrication layer of fresh cement-based composites and PCE dosage is shown in Eq. (7).

$$f_\tau = 118.95 - 42.57\alpha, R^2 = 0.960 \tag{7}$$

The quantitative relationship between the viscosity of the lubrication layer of fresh cement-based composites and PCE dosage is shown in Eq. (8).

$$f_0 = 0.069 - 0.018\alpha, R^2 = 0.967 \tag{8}$$

where, f_s, f_d, f_η, f_τ, and f_o represent the static yield stress, dynamic yield stress, plastic viscosity, lubrication layer yield stress, and lubrication layer viscosity corresponding to the PCE dosage, respectively, and α represents the PCE dosage.

As shown in Figure 9 and Eqs. (4) to (8), the rheological parameters of fresh cement-based composites exhibit a good linear correlation with the PCE dosage, with correlation coefficients ranging from 0.934 to 0.983. As the PCE dosage increases, the static yield stress, dynamic yield stress, plastic viscosity, lubrication layer yield stress, and lubrication layer viscosity of fresh cement-based composites decrease, indicating an increase in the fluidity of the cement-based composites.

3.2 Effect of PCE on the Slump Expansion of Fresh Cement-Based Composites

The effect of different dosages of PCE on the slump expansion of fresh cement-based composites is shown in Figure 10. As can be seen from Figure 10, with the increase in PCE dosage, the slump expansion of fresh cement-based composites gradually increases. When the PCE dosage is 0, the slump expansion of fresh cement-based composites is the smallest, with a minimum value of 475 mm. When the dosage is 1%, the slump expansion reaches its maximum value of 665 mm, an increase of 190 mm, corresponding to a 40% increase.

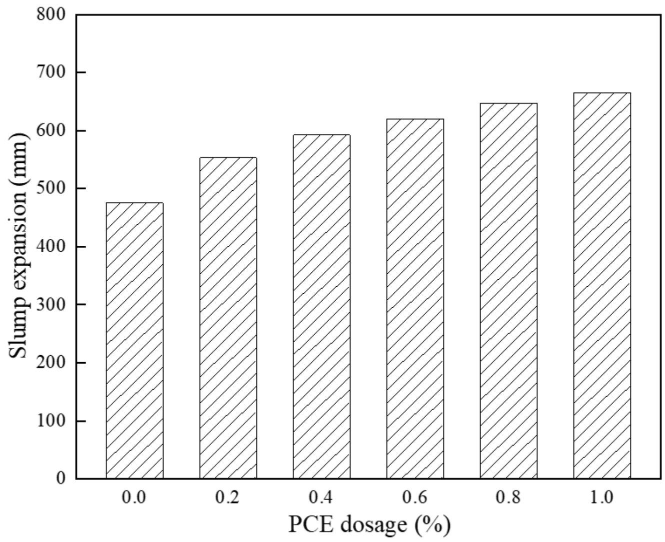


Figure 10. Effects of PCE dosage on slump expansion of fresh cement-based composites

3.3 Effect of PCE on the Bleeding Rate of Fresh Cement-Based Composites

The effect of different dosages of PCE on the bleeding rate of fresh cement-based composites is shown in Figure 11. As can be seen from Figure 11, when the dosage of PCE increases from 0% to 1.0%, the bleeding rate of fresh cement-based composites shows a gradual increasing trend. When the PCE dosage is 0%, 0.2%, 0.4%, 0.6%, 0.8%, and 1.0%, the bleeding rates of fresh cement-based composites are 3.81%, 4.08%, 4.24%, 4.65%, 4.89%, and 5.38%, respectively. When the PCE dosage increases from 0% to 1.0%, the bleeding rate increases by 1.57%.

3.4 Effect of PCE on the Coning Degree of Fresh Cement-Based Composites

The effect of different dosages of PCE on the coning degree of fresh cement-based composites is shown in Figure 12. As shown in Figure 12, with the increase in PCE dosage, the coning degree of fresh cement-based composites gradually increases, while the coning degree difference ΔH gradually decreases.

When the PCE dosage is 0, the coning degree H1 and ΔH of the cement-based composites are 70.65 mm and 7.36 mm, respectively. As the PCE dosage increases to 1.0%, the coning degree H1 increases to 102.50 mm, with an increase of 31.85 mm (45.1%), and ΔH decreases to 3.47 mm, with a decrease of 3.89 mm (52.9%).

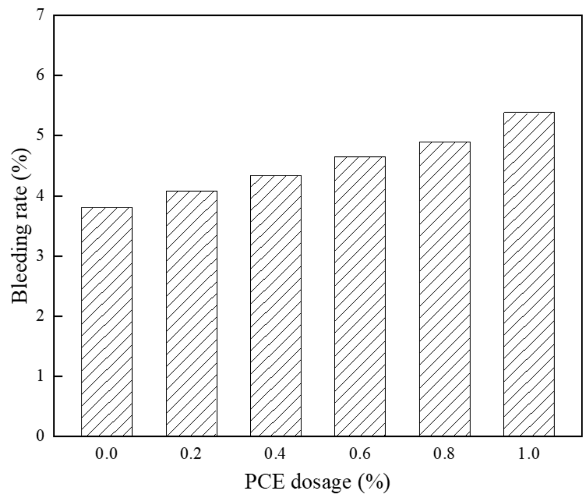


Figure 11. Effects of PCE dosage on bleeding rate of fresh cement-based composites

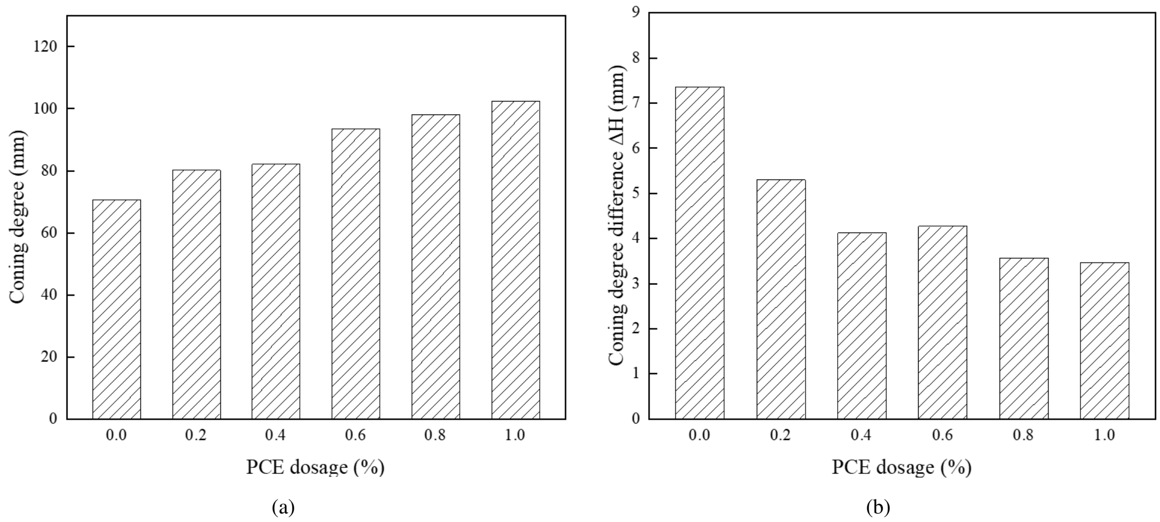


Figure 12. Effects of PCE Dosage on coning degree of fresh cement-based composites (a) Effect of different PCE dosages on coning degree (b) Effect of different PCE dosages on coning degree difference ΔH

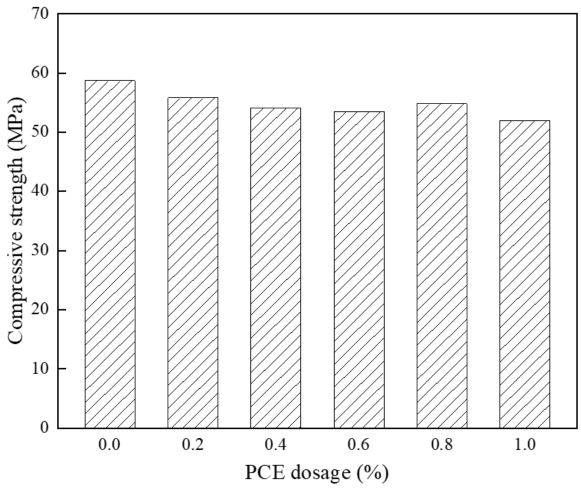


Figure 13. Effect of PCE dosage on compressive strength of cement-based composites

3.5 Effect of PCE on the Compressive Strength of Cement-Based Composites

The effect of different dosages of PCE on the cubic compressive strength of cement-based composites is shown in Figure 13. As shown in Figure 13, the cubic compressive strength of cement-based composites decreases with the increase in the dosage of PCE. When the dosage is 0, the cubic compressive strength of the cement-based composite is 58.7 MPa. When the dosage increases to 1.0%, the compressive strength decreases to 52.0 MPa, with a reduction of 6.7 MPa (11.4%).

In summary, adding PCE slightly reduces the cubic compressive strength of cement-based composites. Since the addition of PCE reduces the water-cement ratio of cement-based composites, this experiment ensures that the water-cement ratio of the mixed system remains unchanged. As the PCE dosage increases, segregation and bleeding of fresh cement-based composites occur, resulting in a decrease in overall integrity and a slight reduction in strength [20–22].

4 Conclusions and Future Prospects

This study investigated the effects of PCE on the workability and mechanical properties of cement-based composites through rheological tests, slump flow tests, bleeding rate tests, consistency tests, and cubic compressive strength tests. The research results can effectively alleviate the contradiction between the workability and strength of cement-based composites, enabling them to better meet actual engineering needs. The main conclusions are as follows:

(1) With the increase in PCE dosage, the static yield stress, dynamic yield stress, and plastic viscosity of fresh cement-based composites gradually decrease, reaching a minimum at a dosage of 1.0%, with reductions of 47.62%, 40.76%, and 48.82%, respectively. This indicates that PCE can significantly improve the rheological properties of fresh cement-based composites.

(2) With the increase in PCE dosage, the slump flow and bleeding rate of fresh cement-based composites gradually increase, and the variation in slump flow and bleeding rate becomes smaller when the dosage is higher. As the dosage of PCE increases, the coning degree of the mixture gradually increases, while the coning degree difference ΔH gradually decreases.

(3) Within a certain range of PCE dosage (0∼1.0%), the mechanical properties of cement-based composites slightly decrease with the increase in dosage. When the dosage increases to 1.0%, the cubic compressive strength of cement-based composites decreases to 52.0 MPa, with a reduction of 11.4%.

To further enhance the performance of cement-based composites and meet the needs of different service environments, several aspects need improvement and further exploration:

(1) This study only explored the effects of PCE on the rheological and mechanical properties of cement-based composites using cement and fly ash as cementitious materials. The performance of cement-based composites can be further improved by adding other mineral admixtures.

(2) Related studies have shown that different types of superplasticizers have different effects on cement-based composites. To simultaneously meet the water-reducing and slump-retaining properties of cement-based composites, further research can be conducted on the effects of compound use of superplasticizers on cement-based composite properties, and sensitivity analysis of different types of superplasticizers can be conducted to explore their significance on cement-based composites.

(3) The study lacks research on the effects of PCE on the structural characteristics of cement-based composites. Subsequent studies can conduct CT analysis tests, mercury intrusion porosimetry to measure pore size distribution and porosity, and reveal the modification mechanism of PCE on cement-based composites.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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