Yuan et al. Int J Concr Struct Mater (2022) 16:50
https://doi.org/10.1186/s40069-022-00534-8

International Journal of Concrete Structures and Materials

RESEARCH Open Access

Research on Modified High-Performance Cement Mortar of Prefabricated Buildings Based on Orthogonal Test

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Abstract

In order to improve the construction technology level of the connection nodes of prefabricated buildings and improve the mechanical properties, fluidity and economy of the connection mortar, this paper adopts the orthogonal experimental design to improve the cement mortar by adding polymer dispersible polymer powder. A modified high-performance mortar with 1d compressive strength of 11Mpa, 3d compressive strength of 19Mpa, 7d compressive strength of 26Mpa, fluidity of 102 mm and final compressive strength higher than M25 was studied. The factors and levels of the orthogonal test are: mortar ratio 1:3,1:4,1:5; silica powder content of 4%,6%,8%; dispersible polymer powder content of 3%,5%,7%. After research, the optimal mixing ratio of modified high-performance mortar is 1:3, the content of silicon powder is 6%, the content of redispersible latex powder is 3%, the content of early strength water reducing agent is 0.1%, and the content of defoamer is 0.5%. The new modified high-performance cement mortar is characterized by short setting time and high early strength, which provides a new idea for the connecting materials of prefabricated buildings, which is of great significance for improving the integrity of prefabricated buildings and the durability of the connection.

Keywords: modified cement mortar, orthogonal test, compressive strength, fluidity, mortar ratio, silica fume content, redispersible latex powder content, optimal mix proportion

1 Introduction

The assembly methods of prefabricated concrete buildings are divided into prefabricated monolithic concrete structures and fully prefabricated concrete structures. In prefabricated buildings, fully prefabricated concrete structures are generally not used because of the load combination problem. Compared with the fully assembled concrete structure, the assembled integral concrete structure has good integrity and earthquake resistance. At present, prefabricated buildings mainly use this structure, and the connection method is wet connection, that is, through various cement mortars for internal Filling and contact connection are used to meet the requirements of on-site construction convenience and ecological environmental protection, to ensure reliable connection between components, and to facilitate the building to be put into operation as soon as possible. Therefore, it is very important to study the reliable performance of cement mortar for the wet connection of prefabricated buildings (Ming, 2017).

In recent years, the rapid deterioration of cement mortar has become a commonly recognized problem in countries all over the world (Ohama, 2006, Ohama & Demura, 2010). Parviz Soroushian et al. Studied the effect of latex on the performance characteristics of carbon fiber reinforced mortar containing silicon powder (Soroushian. et al., 1991). According to the research of many scholars, Mineral admixtures and latexes are added to cement

Journal information: ISSN 1976-0485/eISSN 2234-1315

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mortar during preparation and application. These materials can increase the wear resistance or durability, and reduce the permeability (Yun et al., 2002). Scholars such as Bhikshma, Rozenbaum, Wang, Bhanjaa have conducted various studies on the durability and strength of cement mortar mixed with mineral admixtures and polymers (Bhikshma et al., 2009, Bhanja & Sengupta, 2003, Rozenbaum et al., 2005, Wang et al., 2005). Ohama and Sasse conducted experimental research on the properties and mixing ratio of polymer-modified mortar (Ohama et al., 1986, Ohama Y, 1999, Sasse & Fiebrich, 1983). Ru Wang et al. studied the effect of polymers on the porosity and crackability of cement mortars (Wang et al., 2015). Schulzea et al. found that the compressive strength of modified and unmodified mortars depends on the water–cement ratio and, to a lesser extent, the cement content of the mortar (Schulze, 1999).

In addition, redispersible polymer powders are today's common organic binders to change the properties of dry mortars, especially to improve bond strength due to the formation of polymer films inside the composite (Huimei et al., 2014). Among them, the advantages of redispersible latex powder compared with polymer emulsion in prefabricated buildings are that it does not need to be stored and transported with water, which reduces transportation costs; small packaging volume and light weight; easy to use; storage period Long and easy to keep.

When an appropriate amount of polymer redispersible latex powder is mixed into the cement mortar, its initial hydration rate slows down, and a polymer film is formed to wrap the cement particles, resulting in a certain water-reducing effect. At the same time, the polymer latex powder and the cement form a network structure, greatly enhances the bond strength of cement mortar, reduces the voids of mortar, and its various properties are improved (Longxing, 2016). Jensen and Hansen mainly studied the effect of adding silica fume on the in-situ rechange in hardened cement slurry (Jensen & Hansen, 1995). Choi et al. prepared polymer-modified mortars with various silica fume contents and polymer binder ratios, and proved that the flexural strength, compressive strength and adhesive strength of polymer-modified mortars vary with polymer It increases with the increase of the binder ratio, and reaches the maximum value when the content of silica fume is 4% (Choi et al., 2016). Jiao et al. Studied the effect of different dosage of PP fiber on cement mortar PP fiber was modified by silane coupling agent, and the strength of cement mortar was tested. The results show that compared with unmodified PP fiber, modified PP fiber can more effectively improve the strength of cement mortar (Jiao et al., 2020). Do and Kim studied the fracture mode of PAE modified cement mortar with high fluidity and bond strength under tension, and carried out experiments on unit weight, flow, consistency change, crack resistance and segregation (Do & Kim, 2008).

Many scholars have also conducted in-depth research on the properties of modified mortar. Ru Wang et al. tested the capillary water absorption, impermeability and cracking of three polymer modified cement mortars, and established the correlation between cracking and waterproof performance (Wang et al., 2013). Moreover, Wang et al. studied the effects of curing temperature and humidity on the properties of polymer modified Portland cement mortar and polymer modified calcium sulphoaluminate cement mortar (Wang et al., 2018). Ivanov and Roshavelov studied the rheological properties of modified cement slurry through experiments, and critically analyzed the relative influence of each factor (Ivanov & Roshavelov, 1993). Mirza et al. Repaired the surface of concrete structure damaged by exposure to cold climate through experiments such as thermal compatibility, drying shrinkage, permeability, abrasion resistance, bond strength, compressive strength and freeze–thaw, and evaluated the performance of polymer modified cement-based mortar. Various tests have proved the excellent properties of the modified mortar (Mirza et al., 1997). That is, compared with ordinary cement mortar, the addition of polymer to modify the cement-based material greatly improves its brittleness, shrinkage deformation, poor corrosion resistance and other defects, and is much closer to the site of prefabricated buildings. The actual needs of construction and assembly.

The polymer-modified cement mortar for prefabricated buildings studied in this paper uses ordinary Portland cement as the basic cementitious system, and is mixed with silica fume to form a composite cementitious system. Medium sand is used as fine aggregate, and an appropriate amount of The antifoaming agent, early strength water-reducing agent and redispersible latex powder can be formulated into modified high-performance cement mortar of prefabricated buildings with good fluidity, early strength and fast-hardening, good workability and good mechanical properties. The strength and consistency properties of modified high-performance cement mortar were tested by orthogonal test method. The effects of 1d、3d、7d compressive strength and fluidity were investigated, and the test results were systematically analyzed. Finally, through the analysis of the comprehensive balance method, the best horizontal combination is determined, and the prefabricated building connection materials with high fluidity, short setting time and compressive strength that can meet the strength standard of M25 mortar on the seventh day are obtained.

Table 1 Main performance test table of cement

Cement variety	Setting time(min)		Compressive strength(MPa)		Flexural strength(MPa)	
P.O 42.5	Initial setting time	Final setting time	3d	28d	3d	28d
	78	450	25	51	3.9	8.5

Table 2 Chemical composition of silicon powder

SiO_2(wt %)	Al_2O_3(wt %)	CaO(wt %)	Fe_2O_3(wt %)	MgO(wt %)	Na_2(wt %)
97.15	1.20	0.3	0.25	0.10	1.0

Table 3 Performance indexes of manufactured sand test

Apparent density	Bulk density	Moisture content	Sediment percentage	Fineness modulus
2640 k g/m^3	1510 k g/m^3	4.1%	2.1%	3.54

Table 4 Performance indexes of redispersible latex powder

Solid content/(%)	Ash content at 600 ℃/(%)	Bulk density/(g/L)	Average particle size/(μm)	Minimum film forming temperature /(℃)
98	13	450	80	6

2 Materials and Methods

2.1 Test Materials

The test materials are mainly P.O42.5R type composite Portland cement, Langtian brand silica fume, test sand, WACKER 5020 N redispersible polymer powder, silicone polyether modified silicone defoamer, ash Ba brand concrete early strength superplasticizer, tap water, all test materials meet the requirements of each specification and standard, and the performance indicators are shown in Tables 1, 2, 3, 4 and 5.

2.2 Orthogonal Test Design

In order to reduce the test workload, the orthogonal test design test was used to determine three investigation factors: rubber and sand ratio (factor A), silica powder (factor B), and then dispersing latex powder (factor C), taking three levels per factor, and using orthogonal, Table 9 (34). Table of test factors and levels is shown in Table 6, Mix proportion combination design table of orthogonal test is shown in Table 7.

The compressive strength grade of the designed mortar is M25, and the cement mortar is modified by adding polymer dispersible polymer powder. According to the theoretical dosage of 1m^3 mortar material, the water consumption is 224 kg/m^3, the early strength water reducing agent is 1.65 kg/m^3, and the defoamer is 0.33 kg/m^3, and the mixing ratio of each cubic meter of mortar material is determined by the orthogonal test method, see Table 8.

2.3 Test Piece Production and Test Method

The preparation and test methods of the specimens strictly follow the "Standards for the Test Methods of Basic Properties of Building Mortar" (GJ/T70, 2009), and 9 groups of 70.7 mm × 70.7 mm × 70.7 mm size specimens were prepared first, with 3 pieces in each group; The fluidity value of the mortar was tested at the same time as the specimens were made; the compressive strength was measured when the age of each group of mortar specimens reached 1d, 3d, and 7d.

3 Test Results and Analysis

3.1 Test Results

In order to reflect the characteristics of fast earthwork backfilling of prefabricated buildings, the compressive strength and fluidity values of 9 groups of mortar specimens at 1d, 3d, and 7d ages were measured in this test. The results are shown in Table 9. Among them, the 7d compressive strength reaches more than 16 MPa, reaching 60% of the design strength, and the 28d compressive strength is expected to reach more than 25 MPa, which meets the target requirements of the mortar strength grade M25 determined by the test.

Table 5 Performance index of defoamer

Appearance	Solid content/(%)	Defoaming time/(s)	Stability	PH
White or yellowish at room temperature	30	> 10	3000r / min continuous centrifugation for 15 min without delamination	8

Table 6 Level table of admixture factors

Factor	A	B	C
Horizontal	Gel sand than	Ganister sand (wt%)	Redisperse latex powder (wt%)
1	1:3	4.0	3.0
2	1:4	6.0	5.0
3	1:5	8.0	7.0

Table 7 Mix proportion combination design table of orthogonal test

Number	Combination mode	A Mortar ratio	B Silica fume (wt%)	C emulsion powde (wt%)
1	$A_1B_1C_1$	1:3	4.0	3.0
2	$A_1B_2C_2$	1:3	6.0	5.0
3	$A_1B_3C_3$	1:3	8.0	7.0
4	$A_2B_1C_2$	1:4	4.0	5.0
5	$A_2B_2C_3$	1:4	6.0	7.0
6	$A_2B_3C_1$	1:4	8.0	3.0
7	$A_3B_1C_3$	1:5	4.0	7.0
8	$A_3B_2C_1$	1:5	6.0	3.0
9	$A_3B_3C_2$	1:5	8.0	5.0

3.2 Extreme Difference Analysis

According to the orthogonal test analysis method, the results in Table 8 were processed to obtain the orthogonal test range table, as shown in Tables 10 and 11.

Among them, K_1、K_2、K_3 correspond to the algebraic sum of three groups of mortar test values with the same mortar ratio at three different levels; In the table, $\overline{K_1}$、$\overline{K_2}$、$\overline{K_3}$ correspond to the arithmetic mean of the measured values of three tests at three different levels of factors respectively; Ra represents the range of factors.

It can be found from Table 9 that three groups of level tests were conducted for factor A, namely, three different proportions of mortar and sand ratios (A_1, A_2, A_3), in which each level of factor B and factor C appears only once. B. If there is no interaction between factors C, it will not affect the test index. Therefore, for A_1, A_2 and A_3, the experimental conditions of the three groups of experiments are completely identical. At this time, if factor A has no effect on the test index, then $\overline{K_{A1}}$、$\overline{K_{A2}}$、$\overline{K_{A3}}$ should be equal, but the actual calculation found that $\overline{K_{A1}}$、$\overline{K_{A2}}$、$\overline{K_{A3}}$ are not equal. Therefore, it can be confirmed that the level change of factor A will have an impact on the test index. The arithmetic value of $\overline{K_{A1}}$、、$\overline{K_{A2}}$、$\overline{K_{A3}}$ can reflect the influence degree of A_1, A_2 and A_3 on the test index. Because the measured value of the fluidity of the cement mortar in the test is within the allowable range of the standard, and the better the fluidity of the mortar, the more conducive to ensuring the connection effect of the connection nodes of the prefabricated buildings and the durability of the connection.

. Therefore, it can be concluded that A1 is the optimal level of factor A through $\overline{K_{A1}}>\overline{K_{A2}}>\overline{K_{A3}}$. According to the range R_1、R_2、R_3, it can be judged that the order of primary and secondary influence of the three factors on the test index is ACB.

Similarly, the optimal levels of factor B and factor C are obtained as B_2 and C_2, respectively. Therefore, the optimal combination of flow properties for the connection mortar of prefabricated buildings and the durability of the connection is the ratio of mortar to 1:3, the content of silica fume is 6%, and the content of dispersible polymer powder is 5%.

From Table 10, it can be found that according to the range R_1、R_2、R_3, it can be determined that the primary and secondary influences of the three factors on the test indicators are ACB.

3.3 Factor Index Analysis

According to the orthogonal experimental method, the 1d compressive strength, 3d compressive strength, 7d compressive strength and cement mortar liquidity index will draw the trend chart 1 and test level and liquidity according to Tables 9 and 10, which intuitively shows the influence of the test index (mortar compressive strength and liquidity) Fig. 1 .

As shown in Fig. 2, when the cement mortar ratio changes from 1:3 to 1:4, the compressive strength of 1d decreases by 10.9%, 3d decreases by 20.8%, and 7d decreases by 21.1%; When the mortar ratio changed from 1:4 to 1:5, the compressive strength decreased by 7.7% in 1d, 20.1% in 3d and 11.9% in 7d. When the content of silica fume increased from 4 to 6%, the compressive strength increased by 0.2% in 1d, 1.2% in 3d and 1.2% in 7d; When the content of silica fume increased from 6 to 8%, the compressive strength increased by 0.1% in 1d, decreased by 6.4% in 3d and decreased by 0.1% in 7d. When the content of redispersible latex powder increased from 3 to 5%, the compressive strength decreased by 6.5% in 1d, 4.0% in 3d and 1.1% in 7d; When the content of latex powder increased from 5 to 7%, the compressive strength increased by 0.1% in 1d, 9.0% in 3d and 5.7% in 7d.

As shown in Fig. 3, when the cement sand ratio of cement mortar changes from 1:3 to 1:4, the consistency of cement mortar decreases by 33.2%; When the mortar ratio changes from 1:4 to 1:5, the consistency value increases by 20.2%. When the content of silica fume

Table 8 Mix ratio of mortar materials

Test No	Factor A		Factor B		Factor C		Cement	Sand	Silica fume	Emulsion powder	Water	Early strength water reducer	Defoamer
	Level	Quantity	Level	Quantity	Level	Quantity	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)	(kg)
1#	1	1/3	1	4.0	1	7.0	316.80	950.40	13.20	9.90	224.00	1.65	0.33
2#	1	1/3	2	6.0	2	5.0	310.20	930.60	19.80	16.50	224.00	1.65	0.33
3#	1	1/3	3	8.0	3	7.0	303.60	910.80	26.40	23.10	224.00	1.65	0.33
4#	2	1/4	1	4.0	2	3.0	316.80	1267.20	13.20	16.50	224.00	1.65	0.33
5#	2	1/4	2	6.0	3	7.0	310.20	1240.80	19.80	23.10	224.00	1.65	0.33
6#	2	1/4	3	8.0	1	3.0	303.60	1214.40	26.40	9.90	224.00	1.65	0.33
7#	3	1/5	1	4.0	3	5.0	316.80	1584.00	13.20	23.10	224.00	1.65	0.33
8#	3	1/5	2	6.0	1	7.0	310.20	1551.00	19.80	9.90	224.00	1.65	0.33
9#	3	1/5	3	8.0	2	5.0	303.60	1518.00	26.40	16.50	224.00	1.65	0.33

Table 9 Compressive strength and flubility of mortar

Test number	Metric			
	1d compressive strength (MPa)	**3d compressive strength (MPa)**	**7d compressive Strength (MPa)**	**Liquidity value (mm)**
1#	9.54	18.05	25.50	99
2#	8.91	15.85	23.75	107
3#	8.28	16.00	24.31	77
4#	7.28	12.11	17.95	59
5#	8.03	15.36	21.48	64
6#	8.50	12.05	18.62	66
7#	7.31	10.73	17.18	69
8#	7.25	10.16	16.12	75
9#	7.44	10.68	17.86	83

Table 10 Analysis of mortar fluidity

Test number	Factor			Test result
	A	**B**	**C**	**flowability(mm)**
1	1(1:3)	1(4.0)	1(3.0)	99
2	1(1:3)	2(6.0)	2(5.0)	107
3	1(1:3)	3(8.0)	3(7.0)	77
4	2(1:4)	1(4.0)	2(5.0)	59
5	2(1:4)	2(6.0)	3(7.0)	64
6	2(1:4)	3(8.0)	1(3.0)	66
7	3(1:5)	1(4.0)	3(7.0)	69
8	3(1:5)	2(6.0)	1(3.0)	75
9	3(1:5)	3(8.0)	2(5.0)	83
K_1	283	227	240	$\sum$=699
K_2	189	246	249	
K_3	227	226	210	
$\overline{K_1}$	94.3	75.7	80.0	
$\overline{K_2}$	63.0	82.0	83.0	
$\overline{K_3}$	75.7	75.3	70.0	
Excellent level	A_1	B_2	C_2	
Ra	31.3	6.7	13.0	
Primary and secondary order	ACB			

increases from 4 to 6%, the consistency value increases by 8.3%; When the content of silica fume increased from 6 to 8%, the consistency value decreased by 8.2%. When the content of redispersible latex powder increased from 3 to 5%, the consistency value increased by 3.8%; When the content of latex powder increased from 5 to 7%, the consistency value decreased by 15.7%.

As can be seen from Fig. 4, rubber–sand ratio is the main factor affecting the compressive strength of mortar at 1d, 3d and 7d, while redispersing latex powder is an important factor, and silicon powder mixing is the secondary factor, that is, the order of primary and secondary influence is A > C > B.

As can be seen from Fig. 5, rubber sand ratio is the main factor affecting the fluidity of mortar, and redispersing latex powder is an important factor, and the amount of silicon powder is the secondary factor, that is, the order of primary and secondary influence is A > C > B.

In conclusion, it can be found that different silicon powder mixing has almost little impact on the 1d compressive strength of polymer modified mortar. The compressive strength of mortar at 3d and 7d of age will first increase with the increase of silicon powder incorporation. Therefore, the optimal amount of silicon powder in this test is near 6%. The main reason is that silica powder can fill cement particles with dispersion; and silica powder is rich in SiO_2, The strength of the cement mortar is improved by the hydration reaction.

The impact of different rubber sand ratio on the compressive strength of mortar is basically the same, and with the increasing ratio of rubber sand, the compressive strength of cement mortar will decrease sharply. At the same time, the ratio of rubber sand on the mortar liquidity and the compressive strength of mortar is much greater than the redisperse latex powder and silicon powder. The main reason is that sand is one of the three main materials forming cement mortar. Meanwhile, sand, as a fine aggregate in cement mortar, plays the role of skeleton and connection, so sand plays an important role in the mechanical properties and internal structure of cement mortar (Xiaoguo, 2020). The mechanical properties and ease of rubber sand ratio of 1:3 are greatly ahead of other rubber sand ratio.

With the increase of redispersed latex powder mixing amount, the compressive strength of cement mortar will decline first and then rise, and the fluidity of

Table 11 Analysis of extreme compressive strength of mortar

	A	B	C	1d	3d	7d
1	1(1:3)	1(4.0)	1(3.0)	9.54	18.05	25.50
2	1(1:3)	2(6.0)	2(5.0)	8.91	15.85	23.75
3	1(1:3)	3(8.0)	3(7.0)	8.28	16.00	24.31
4	2(1:4)	1(4.0)	2(5.0)	7.28	12.11	17.95
5	2(1:4)	2(6.0)	3(7.0)	8.03	15.36	21.48
6	2(1:4)	3(8.0)	1(3.0)	8.50	12.05	18.62
7	3(1:5)	1(4.0)	3(7.0)	7.31	10.73	17.18
8	3(1:5)	2(6.0)	1(3.0)	7.25	10.16	16.12
9	3(1:5)	3(8.0)	2(5.0)	7.44	10.68	17.86
1d Resist press stubborn linear measure						
K_1	26.73		24.13		25.29	
K_2	23.81		24.19		23.63	
K_3	22.00		24.22		23.62	
$\overline{K_1}$	8.91		8.04		8.43	
$\overline{K_2}$	7.94		8.06		7.88	
$\overline{K_3}$	7.33		8.07		7.87	
Ra	1.58		0.03		0.56	
Excellent level	A_1		B_3		C_1	
Primary and secondary order	ACB					
3d Resist press stubborn linear measure						
K_1	49.90		40.89		40.26	
K_2	39.52		41.37		38.64	
K_3	31.57		38.73		42.09	
$\overline{K_1}$	16.63		13.63		13.42	
$\overline{K_2}$	13.17		13.79		12.88	
$\overline{K_3}$	10.52		12.91		14.03	
Ra	6.11		0.88		1.15	
Excellent level	A_1		B_2		C_3	
Primary and secondary order	ACB					
7d Resist press stubborn linear measure						
K_1	73.56		60.63		60.24	
K_2	58.05		61.35		59.56	
K_3	51.16		60.79		62.97	
$\overline{K_1}$	24.52		20.21		20.08	
$\overline{K_2}$	19.35		20.45		19.85	
$\overline{K_3}$	17.05		20.26		20.99	
Ra	7.47		0.24		1.14	
Excellent level	A_1		B_2		C_3	
Primary and secondary order	ACB					

cement mortar will increase first and then decrease with the increase of latex powder mixing amount. Through the comprehensive analysis of polymerizable latex powder, the test of latex powder mixing near 3%, polymer latex powder can slow down the initial hydration rate of mortar, forming viscosity and continuity of polymer microfiber film wrapped cement particles, produce certain water reduction effect, at the same time, polymer film and cement form a certain elastic network structure (Bo Wang, 2014), It greatly improves the deformation capacity of cement mortar, reduces the gap of mortar, thus improving the performance of cement mortar.

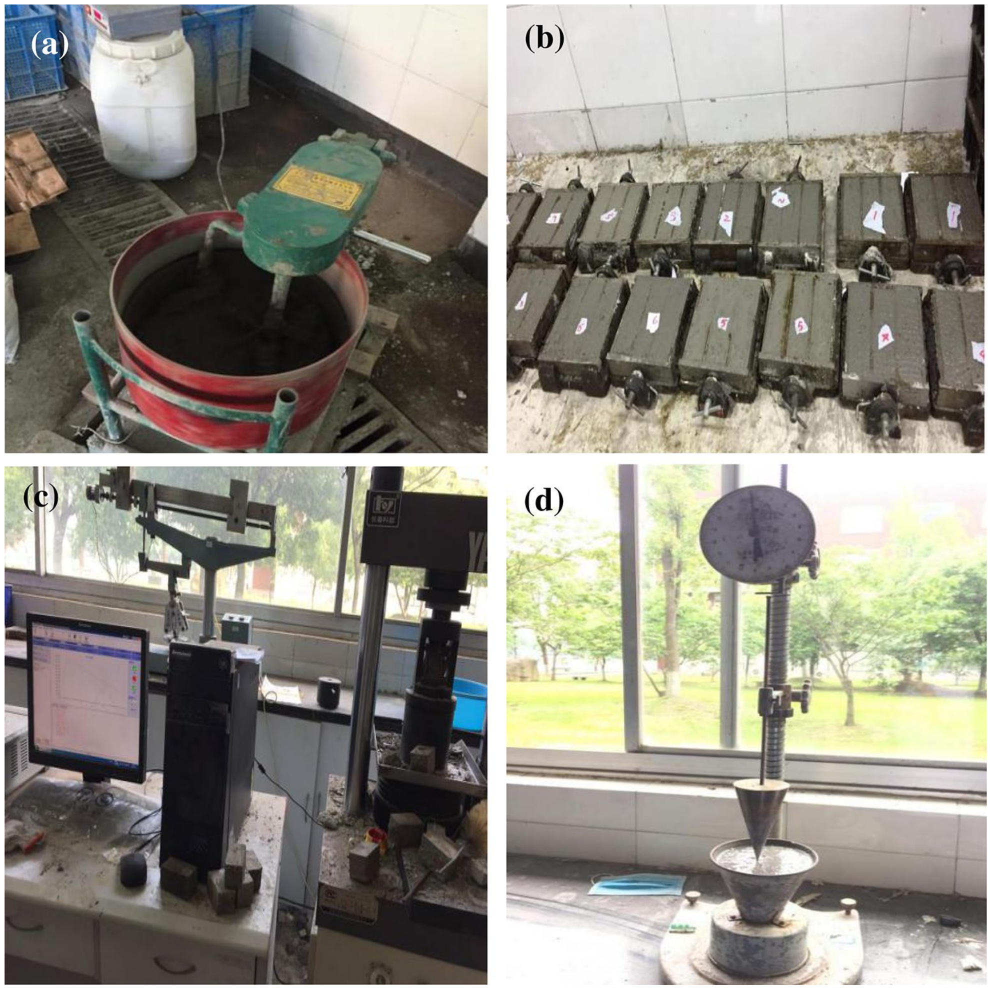

Fig. 1 **a** Mortar mixing. **b** Mortar molding. **c** Determination of compressive strength of mortar. **d** Determination of mortar consistency value.

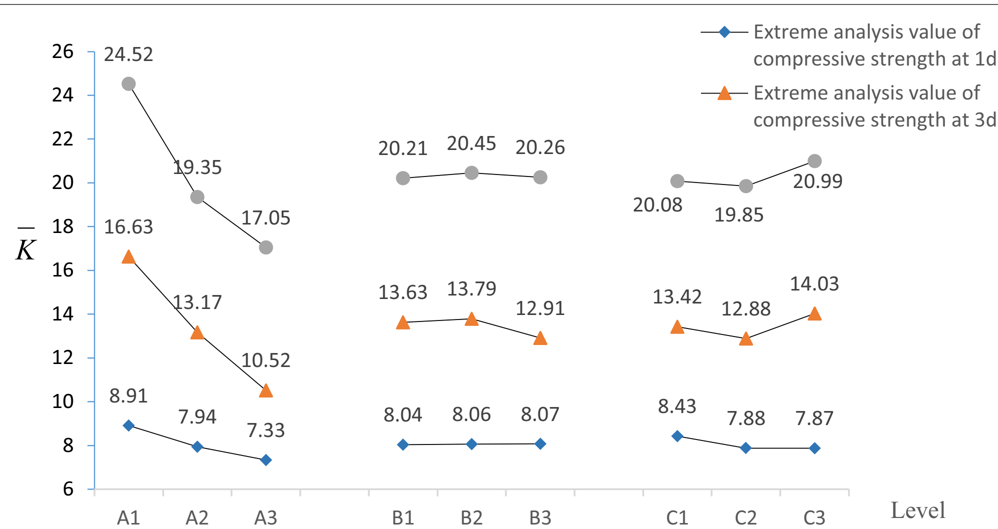

Fig. 2 Relationship between factors and factor under compressive strength $\overline{K}$.

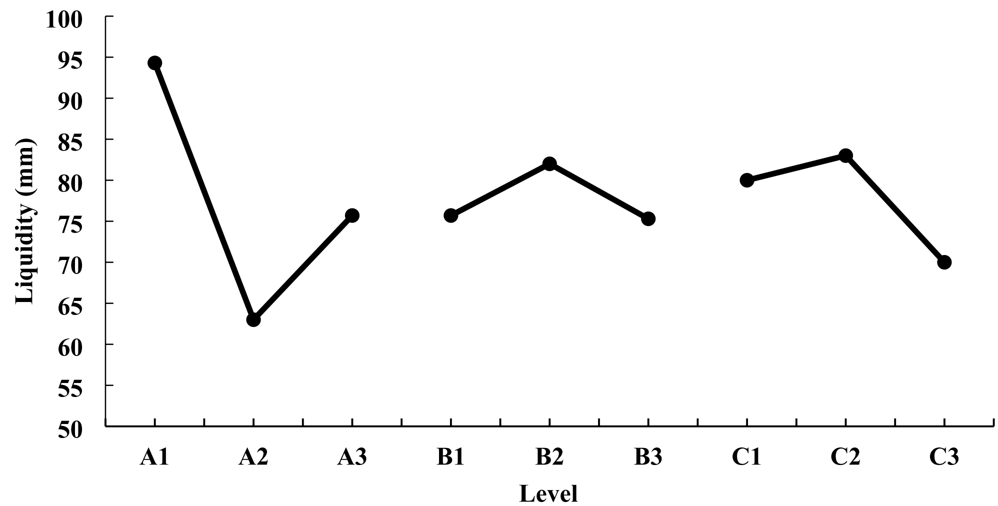

Fig. 3 Relationship between the cement mortar mobility and the mixing volume of various factors.

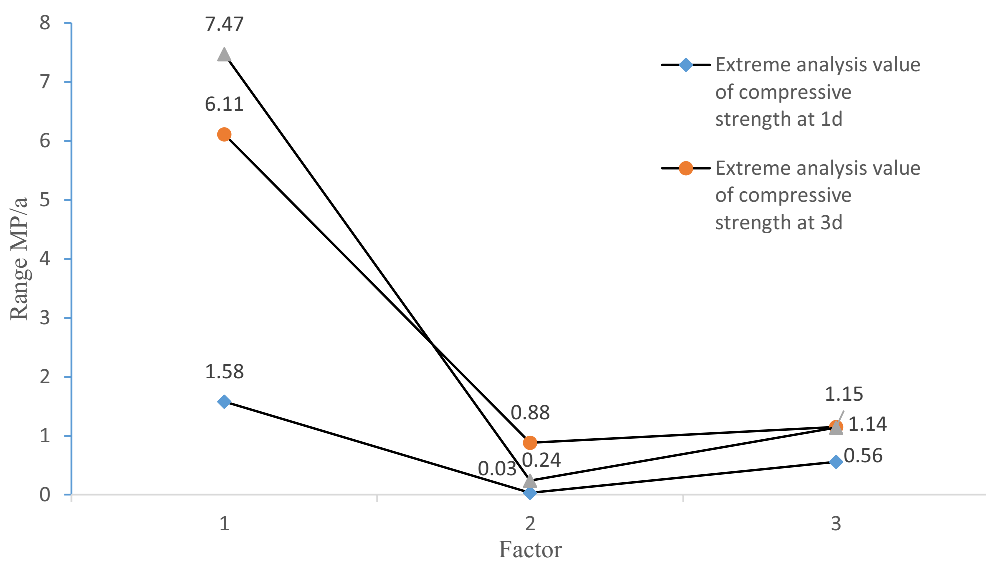

Fig. 4 Analysis value of each compressive strength.

3.4 Analysis of Variance

ANOVA for the results of modified high-performance mortar fluidity, 1d compressive strength, 3d compression strength and 7d compressive strength are shown in Tables 12, 13, 14 and ,15 respectively.

From Tables 12, 13, 14 and 15 and the rubber–sand ratio is the main factor affecting the mortar mobility and the compressive strength of 1d, 3d and 7d, which can disperse the latex powder again, and the latex powder has the smallest impact of the silicon powder, which is consistent with the results of the extreme difference analysis.

Extreme analysis does not distinguish data fluctuations caused by changing test conditions and data fluctuations caused by error (Cai & Wang, 1985), To further confirm the influence of the factors on the index, the calculation of the factor contribution rate was analyzed. Tables16, 17, 18 and 19, and show the result table of the contribution rate of factors and errors.

It can be seen from Table 16 that the mortar-to-sand ratio has the greatest influence on the fluidity of the mortar, and the data fluctuation caused by its level change accounts for 35.53% of the total square sum of

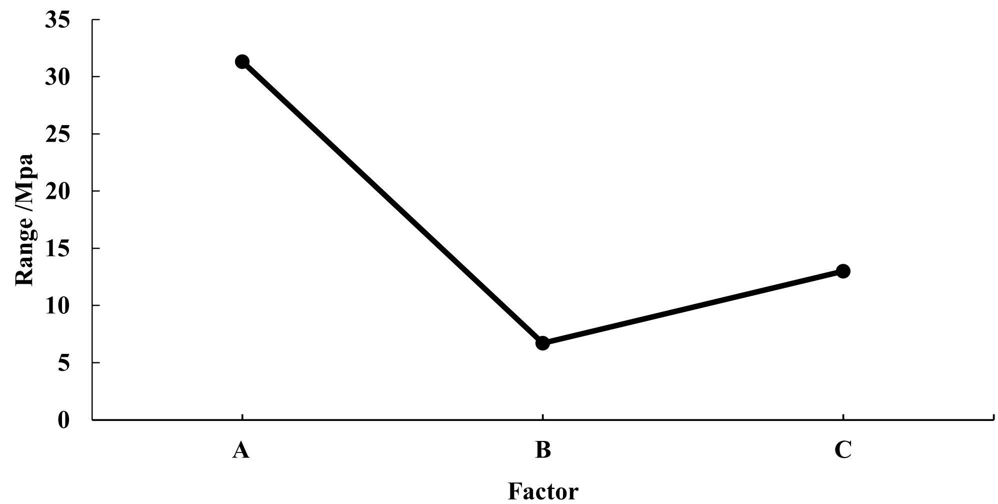

Fig. 5 Analysis value of mortar liquidity.

Table 12 ANOVA of liquidity test results

Factor	Sum of square of deviation	Degrees of freedom	Mean square	*F*	F Critical value	Significance
A	1490.667	2	745.333	6.093	$F_{0.05}(2,8) = 4.46$	*
B	84.667	2	42.333	3.346	$F_{0.1}(2,8) = 3.11$	*
C	278	2	139	4.136	$F_{0.1}(2,8) = 3.11$	*

Table 13 ANOVA of the results of the 21 d compressive strength test

Factor	Sum of square of deviation	Degrees of freedom	Mean square	*F*	F Critical value	Significance
A	3.797	2	1.899	4.987	$F_{0.05}(2,8) = 4.46$	*
B	0.001	2	0.001	3.151	$F_{0.1}(2,8) = 3.11$	*
C	0.616	2	0.308	3.647	$F_{0.1}(2,8) = 3.11$	*

Table 14 ANOVA of the results of the 33 d compressive strength test

Factor	Sum of square of deviation	Degrees of freedom	Mean square	*F*	F critical value	Significance
A	56.326	2	28.163	7.944	$F_{0.025}(2,8) = 6.06$	*
B	1.318	2	0.659	3.186	$F_{0.1}(2,8) = 3.11$	*
C	1.986	2	0.993	4.68	$F_{0.05}(2,8) = 4.46$	*

pure deviations, which is 6.09 times the data fluctuation caused by the error; The contribution of the data fluctuation caused by the level change of the redispersed polymer powder is also larger than that caused by the error; the data fluctuation caused by the level change of the silicon powder is far less than that caused by the error, so it can be considered as unimportant.

It can be seen from Table 17 that the mortar-to-sand ratio has the greatest influence on the 1d compressive strength, and the data fluctuation caused by its level

Table 15 ANOVA of the results of the 47 d compressive strength test

Factor	Sum of square of deviation	Degrees of freedom	Mean square	*F*	F critical value	Significance
A	87.755	2	43.877	11.111	$F_{0.005}(2,8) = 11.04$	*
B	0.095	2	0.048	3.512	$F_{0.1}(2,8) = 3.11$	*
C	2.171	2	1.086	6.275	$F_{0.025}(2,8) = 6.06$	*

Table 16 Results of the contribution rate of factors and errors under mortar fluidity

Factor	Sum of square of deviation	Degrees of freedom	Sum of square of pure deviation	Contribution rate %
A	1490.667	2	745.333	35.53
B	84.667	2	42.333	2.02
C	278	2	139	6.63
Error	244.667	2	122.333	5.83
Sum	2098	8		

Table 17 Contribution rate results of factors and errors under compressive strength at 16 1d

Factor	Sum of square of deviation	Degrees of freedom	Sum of square of pure deviation	Contribution rate %
A	3.797	2	1.899	35.38
B	0.001	2	0.001	0.02
C	0.616	2	0.308	5.74
Error	0.952	2	0.476	8.87
Sum	5.367	8		

Table 18 Contribution results of factors and errors under the 73 d compressive strength

Factor	Sum of square of deviation	Degrees of freedom	Sum of square of pure deviation	Contribution rate %
A	56.326	2	28.163	42.21
B	1.318	2	0.659	0.99
C	1.986	2	0.993	1.49
Error	7.09	2	3.545	5.31
Sum	66.721	8		

change accounts for 35.38% of the total square sum of pure deviations, which is 3.99 times the data fluctuation caused by the error.; The data fluctuation caused by the level change of the redispersible polymer powder is less than the data fluctuation caused by the error;

Table 19 Contribution results of factors and error under compressive strength at 87 d

Factor	Sum of square of deviation	Degrees of freedom	Sum of square of pure deviation	Contribution rate %
A	87.755	2	43.877	44.81
B	0.095	2	0.048	0.05
C	2.171	2	1.086	1.11
Error	7.898	2	3.949	4.03
Sum	97.92	8		

Table 20 Order table of the primary and secondary influences of each factor

Test index	Main → Secondary
1d compressive strength (MPa)	A C B
3d compressive strength (MPa)	A C B
7d compressive Strength (MPa)	A C B
Liquidity value (mm)	A C B

Table 21 Primary-based optimal level combination

Optimum horizontal combination of the primary elections		
1d compressive strength (MPa)	$A_1B_3C_1$	High strength is the best
3d compressive strength (MPa)	$A_1B_2C_3$	High strength is preferred
7d compressive Strength (MPa)	$A_1B_2C_3$	High strength is the best
Liquidity value (mm)	$A_1B_2C_2$	Better with great liquidity

It can be seen from Table 18 that the mortar-to-sand ratio has the greatest influence on the 3d compressive strength, and the data fluctuation caused by its level change accounts for 42.21% of the total square sum of pure deviations, which is 7.95 times the data fluctuation caused by the error.; The data fluctuation caused by the level change of the redispersible polymer powder is less than the data fluctuation caused by the error;

It can be seen from Table 19 that the mortar-to-sand ratio has the greatest influence on the 7d compressive strength, and the data fluctuation caused by its level change accounts for 44.81% of the total square sum of pure deviations, which is 11.12 times the data fluctuation caused by the error.; The data fluctuation caused by the level change of the redispersible polymer powder is less than the data fluctuation caused by the error.

4 Optimal Level Combination Was Determined

According to the factor index analysis, the primary and secondary order of each factor is listed in Table 20, and it is analyzed by the comprehensive balance method to determine the optimal level combination. Combination of optimal primary levels are shown in Table 21.

It can be seen from Table 21 that the optimal level for the A factor is A_1; while the B factor and C factor need to comprehensively consider the order of primary and secondary influences on the test indicators to determine the optimal level, and finally obtain the optimal level combination of the test.

For factor B: in terms of the primary and secondary order, the impact on the test index is ranked at the bottom, that is, the degree of influence on the test index is smaller than that of the other two factors. It needs to be analyzed from a quantitative point of view, that is, the compressive strength value. When B_2 is selected, the 1d compressive strength is 0.01% lower than that of B_3 (unfavorable); the 3d compressive strength is 6.8% higher than that of B_3 (favorable); the 7d compressive strength is higher than that of B_3 When B_3 is selected, the 1d compressive strength is 0.01% higher than that of B_2 (favorable); the 3d compressive strength is 6.4% lower than that of B_2 (unfavorable); The 7d compressive strength is 0.01% lower than that of B_2 (unfavorable); the fluidity value is 8.2% lower than that of B_2 (unfavorable). To sum up, it is obvious that B_2 is the better choice, see Table 22 for details.

For factor C: the impact on the test indicators is ranked second from the perspective of primary and secondary order, and it still needs to be considered and analyzed from a quantitative point of view. When C_1 is selected, the 1d compressive strength is 7.0% and 7.1% higher than C_2 and C_3 respectively (favorable); the 3d compressive strength is 4.2% higher (favorable) and 4.3% lower (unfavorable) than C_2 and C_3 respectively; The compressive strength is 1.1% higher (favorable) and 4.3% lower (unfavorable) than C_2 and C_3 respectively; the fluidity value is 3.6% lower (unfavorable) and 14.3% higher (favorable) than C_2 and C_3, respectively. When C_2 is selected, the 1d compressive strength is 6.5% lower and 0.01% higher than that of C_1 and C_3 respectively; the 3d compressive strength is 4.0% and 8.2% lower than that of C_1 and C_3 respectively (unfavorable); the 7d compressive strength is higher than that of C_1 and C_3 respectively Decreases by 1.1% and 5.4% (unfavorable); the liquidity value is higher than C_1 and C_3 by 3.8% and 18.6% (favorable) respectively. When C_3 is selected, the 1d compressive strength is 6.6% and 0.01% lower than that of C_1 and C_2 respectively (unfavorable); the 3d compressive strength is 4.5% and 8.9% higher than that of C_1 and C_2 respectively (favorable); the 7d compressive strength is respectively higher than that of C_1, C_2 are 4.5% and 5.7% higher (favorable); the liquidity value is lower than C_1, C_2 by 12.5% and 15.7% (unfavorable). To sum up, it is obvious that C_1 is better, see Table 23 for details.

Table 22 B Comprehensive balance of factors

B factor	Advantageous	Unfavourable
B_2	15.71%	0.01%
B_3	0.01%	14.61%

Table 23 A Factors' comprehensive balance

C factor	Advantageous	Unfavourable
C_1	33.70%	12.20%
C_2	22.41%	25.20%
C_3	23.60%	34.81%

In conclusion, the optimal level combination of this trial is $A_1B_2C_1$That is, the rubber sand ratio of 1:3, silicon powder mixing 6%, can disperse latex powder mixing 3%.

5 Validation Test

The optimal level combination analyzed according to the orthogonal test scheme is not in the above 9 sets of tests, so an optimal level combination test of rubber sand ratio of 1:3,6% silicon powder mixing can disperse latex powder mixing of 3%.Specific test detection data are shown in Table 24.

According to Table 24, the compressive strength of polymer-modified cement mortar under the optimal horizontal combination reached 11 MPa, 7d 26 MPa, and 102 mm. Both in terms of mechanical performance or liquidity, the mortar. Performance meets the construction materials of the joint node of prefabricated building,

Table 24 Validation of the test results

Optimal level combination	1d compressive strength (MPa)	3d compressive strength (MPa)	7d compressive Strength (MPa)	Liquidity value (mm)
$A_1B_2C_1$	11.02	19.88	26.47	102

realize earthwork backfilling as soon as possible and accelerate the on-site installation progress.

6 Conclusions

(1) Research on the modification of cement mortar by adding polymer redispersible latex powder, adding silica fume, early strength water reducing agent and defoaming agent at the same time, and improving the cement mortar by adjusting the mortar ratio of cement mortar. Mechanical properties, fluidity. Using a three-factor and three-level orthogonal experimental design, the optimal mixing ratio was determined as the mortar ratio of 1:3, the content of silica powder 6%, the content of redispersible latex powder 3%, and the content of early strength superplasticizer 0.1%. The content of defoamer is 0.5%.

(2) Range analysis, variance analysis and significance test were used to test the effect of each group on the fluidity of mortar and the compressive strength of 1d, 3d, and 7d respectively: A (mortar ratio) > C (redispersible polymer powder) > B (silicon fume).

(3) The factor contribution rate was used to calculate the degree of influence of each group on the fluidity of mortar and the compressive strength of 1d, 3d, and 7d under the data fluctuation caused by the level change: A (mortar ratio) > C (redispersible latex powder)) > B (silicon powder).

(4) Under the optimal level combination determined from the aspects of mechanical properties, the 1d compressive strength of polymer modified cement mortar reached 11mpa, 3d compressive strength reached 19mpa, 7d compressive strength reached 26mpa. It meets the requirements of construction materials at the connection joints of prefabricated buildings, realizes the short setting time of mortar, and the compressive strength has reached the M25 mortar strength standard on the seventh day, speeding up the on-site installation progress.

(5) The fluidity of polymer modified cement mortar under the optimal level combination determined from the aspect of fluidity reaches 102 mm. It ensures that the mortar has high consistency and good fluidity, and it is not easy to produce segregation and bleeding during storage, transportation and construction.

Author contributions

CBY guides papers and experiments, YC analyzes data and compiles papers, QG compiles papers, and DS perfects papers. All authors read and approved the final manuscript.

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Funding

This research work was supported by the Jiangsu Provincial Department of Water Resources, Project name: Jiangsu Water Conservancy Science and Technology Project, Project number: 2019037.

Data availability

The data used in the article can be obtained from the corresponding author.

Declarations

Competing interests

The authors declare no conflict of interest with other authors and researchers.

Received: 2 March 2022 Accepted: 15 May 2022
Published online: 23 September 2022

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