

## The orthogonal experiment research on premixed wet mortar

Hengchun Zhang<sup>1,a</sup>, Xixian Ji<sup>1,b</sup>, Xiaoqing Zheng<sup>1,c\*</sup>, Kaibo Zou<sup>1,d</sup> and Changwen Zhang<sup>1,e</sup>

<sup>1</sup>China State Construction Ready Mixed Concrete Fujian Co. Ltd., Fuzhou, China

<sup>a</sup>115076527@qq.com, <sup>b</sup>290634171@qq.com, <sup>c</sup>suany2@126.com, <sup>d</sup>wwwzkb@163.com, <sup>e</sup>1748119837@qq.com

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**Abstract.** As a new kind of environmental protection building material, premixed wet mortar possesses a wide application prospect. The technical difficulty is to maintain the workability of premixed wet mortar as long as construction required setting time by choosing suitable raw materials and mix proportion. In this paper, the effect of water-binder ratio, sand type, the type and content of admixture were investigated using orthogonal experiment in respect of consistency, setting time, water-retention rate, compressive strength, etc. The range value and the most significant factor were obtained based on the range analysis, and the mix proportion is optimized.

### Introduction

With the rapid development of Chinese new urbanization and the compulsive requests of the construction of civilization, energy efficiency and environmental protection, mortar mixing at construction sites have been prohibited. Environment-friendly building materials are expected. As a new kind of environmental protection building material, premixed wet mortar has attracted a wide spread attention. Premixed wet mortar is mixture in a certain proportion by means of a professional manufacturer. The raw materials are weighed accurately before mixing process. The application of premixed wet mortar may reduce dust pollution, improve engineering quality and speed up the construction. Therefore, the production and application of premixed wet mortar is one of the most important way for the effective promotion of circulation economy, energy conservation and emission reduction<sup>[1]</sup>.

However, the loss of consistency and mortar set are likely to happen during the transportation and storage. Such problems of poor stability of quality may seriously affect the application of premixed wet mortar. In recent years, the technical difficulty has been investigated. One of the solutions is to use mortar admixture, which may keep the workability of mortar as long as 24 hours, meanwhile has no negative effect on the setting and hardening of the mortar after construction<sup>[2,3]</sup>. On the other hand, the consistency, setting time and water-retention rate are also affected by mix proportion, raw materials, etc<sup>[4]</sup>. Up to now, few researches about the influence of raw materials on the performance of premixed wet mortar have been carried out. In this paper, the effect of the water-binder ratio, sand type, the type and content of admixture were investigated using orthogonal experiment in respect of consistency, setting time, water-retention rate, compressive strength, etc, from which the range value and the most significant factor were obtained, the mix proportion was optimized.

### Experiment program

**Raw materials.** Ordinary portland cement 42.5 was used. The fundamental performance parameters of the cement are shown in Table 1. Fly ash, with grade II, had a fineness of 18.0%, loss on ignition of 4.7% and water demand ratio of 96%. Three different types of fine aggregates, including machine-made sand (MMS), intermediate standard sand (ISS) and fine river sand (FRS), were sieved using a square hole sieve with a nominal diameter of 5mm. MS had a fineness modulus of 3.0 and a silt content of 4.8%, while FRS had a fineness modulus of 1.7 and a silt content of 2.0%. Three different types of admixtures, including Y<sub>1</sub>, Y<sub>2</sub>, Y<sub>3</sub>, were taken from Guangzhou, Changsha and Suzhou, respectively. The components of admixtures contained retarder and water reducer. Among

the three admixtures,  $Y_1$  was composed of retarder ( $Y_{11}$ ) and water reducer ( $Y_{22}$ ), both of which were liquids, while  $Y_2$  and  $Y_3$  were powders. The water used is distilled water.

Table 1 The fundamental performance parameters of cement

Specific surface area ( $\text{m}^2/\text{kg}$ )	The standard consistency water (g)	Stability	Setting time (min)		Flexural strength (MPa)		Compressive strength (MPa)	
			Initial set	Final set	3d	28d	3d	28d
365	138	qualified	150	180	6.5	9.1	29.9	49.5

**Methods.** Consistency, setting time, water-retention rate and compressive strength of premixed wet mortar were tested by the method of GB/T2518-2010 (Premixed mortar), JGJ/T 220-2010 (Technical specification for plastering mortar) and JGJ/T 70-2009 (Standard for test method of performance on building mortar).

**Orthogonal experimental design.** The aims of the orthogonal experiment were to find the most important experimental factor on the performance of the premixed wet mortar, and to detect the optimum parameters to produce premixed wet mortar. According to the preliminary experimental experience, four factors shown as follows: A (water-binder ratio), B (sand type), C (admixture type) and D (content of admixture) were chosen as the experimental factors. Each factor included three levels (shown in Table 2). Levels of factor A included 0.71, 0.63 and 0.56. Levels of factor B included MMS, ISS and mixed sand (MS, contained 60% MMS and 40% FRS, and had a fineness modulus of 2.4). Levels of factor C included admixture  $Y_1$ ,  $Y_2$ ,  $Y_3$ . Levels of factor D based on the recommended dosage ( $\pm(0.5\%-1.0 \text{ wt.}\%)$  of binding material). An orthogonal matrix noted as  $L_9(3^4)$  (shown in Table 3) was chosen as the experimental scheme to arrange the experiment.

Table 2 The variables design

Factor	A	B	C	D (wt.%)			
				$Y_1$		$Y_2$	$Y_3$
				$Y_{11}$	$Y_{12}$		
Level							
a	0.71	MMS	$Y_1$	0.90	3.4	0.40	0.50
b	0.63	ISS	$Y_2$	1.00	3.4	0.45	0.55
c	0.56	MS	$Y_3$	1.10	3.4	0.50	0.60

Table 3  $L_9(3^4)$  orthogonal experimental design table

NO.	Factor				Amounts of materials ( $\text{kg}/\text{m}^3$ )						
	A	B	C	D	Cement	Fly ash	MSS	FRS	ISS	Water	Admixture
1	a	a	a	a	230	80	1400	0	0	220	$Y_{11}:2.79$ $Y_{12}:10.54$
2	a	b	b	b	230	80	0	0	1400	220	1.40
3	a	c	c	c	230	80	840	560	0	220	1.86
4	b	a	b	c	270	80	1380	0	0	220	1.75
5	b	b	c	a	270	80	0	0	1380	220	1.75
6	b	c	a	b	270	80	828	552	0	220	$Y_{11}:3.50$ $Y_{12}:11.90$
7	c	a	c	b	310	80	1370	0	0	220	2.14
8	c	b	a	c	310	80	0	0	1370	220	$Y_{11}:4.29$ $Y_{12}:13.26$
9	c	c	b	a	310	80	822	548	0	220	1.56

## Experiment results and analysis

**Orthogonal experiment results.** The results of consistency, setting time, water-retention rate and compressive strength of premixed wet mortar are summarized in Table 4.

Table 4 The results of the orthogonal experiment

NO.	Consistency (mm)	Setting time (h)	Water-retention (%)	Compressive strength (MPa)	
				7d	28d
1	77	6	89.3	14.9	21.6
2	102	9	90.7	3.5	6.9
3	40	45	99.3	8.8	16.7
4	64	3.5	96.2	17.6	17.4
5	107	113	95.9	3.9	8.6
6	76	19	93.5	12.2	19.0
7	65	50	96.9	26.1	34.1
8	113	62	89	5.7	15
9	47	4	98.5	21.9	34.6

**Range analysis.** The optimum levels of all factors and optimal mix proportion could be determined by range analysis. The K values and the range values were calculated (exhibited in Table 5). The K value for each level of a factor is the average of three values of samples with the same level. The range value for each factor is the difference between the maximal and minimal values of the three level. The most significant factor has the highest range value. The optimal level is confirmed on the basis of construction requirements on the performance of premixed wet mortar. For instance, the consistency of premixed wet plaster mortar is 70-90 mm, the water-retention rate must be above 88%, and setting time should be longer than 24 hours. According to the order of significant factor and corresponding optimal level for each performance, the optimal mix proportion of premixed wet mortar was selected.

Table 5 The results of range analysis

Performance	Factor	K value			Range value	Optimum parameter
		k <sub>a</sub>	k <sub>b</sub>	k <sub>c</sub>	R	
Consistency	A	73.0	82.3	75.0	9.3	B <sub>a</sub> C <sub>a</sub> A <sub>b</sub> D <sub>b</sub>
	B	68.7	107.3	54.3	53.0	
	C	88.7	71.0	70.6	18.1	
	D	77.0	81.0	72.3	8.7	
Setting time	A	20.0	45.1	38.7	25.1	C <sub>a</sub> B <sub>c</sub> A <sub>a</sub> D <sub>b</sub>
	B	19.8	61.3	22.7	41.5	
	C	29.0	5.5	69.3	63.8	
	D	41.0	26.0	36.8	15.0	
Water-retention rate	A	93.1	95.2	94.8	2.1	C <sub>c</sub> B <sub>c</sub> D <sub>c</sub> A <sub>b</sub>
	B	94.1	91.9	97.1	5.2	
	C	90.6	95.1	97.3	6.8	
	D	94.6	93.7	94.8	1.1	
28d compressive strength	A	15.1	15.0	27.9	12.9	B <sub>a</sub> A <sub>c</sub> D <sub>a</sub> C <sub>c</sub>
	B	24.4	10.2	23.4	14.2	
	C	18.5	19.6	19.8	1.3	
	D	21.6	20.0	16.4	5.2	

Figure 1 depicts intuitively the range value of each factor in respect of consistency, setting time, water-retention rate and compressive strength. For the consistence of premixed wet mortar, the most significant factor is sand type, followed by admixture type. Water-binder ratio and content of admixture have similar degree of influence. The optimum parameter is  $B_a C_a A_b D_b$ . For setting time and water-retention rate, the most significant factor is admixture type, while sand type and water-binder ratio become the most important factors for compressive strength. The optimum parameters for setting time, water-retention rate and compressive strength are  $C_a B_c A_a D_b$ ,  $C_c B_c D_c A_b$  and  $B_a A_c D_a C_c$ , respectively.

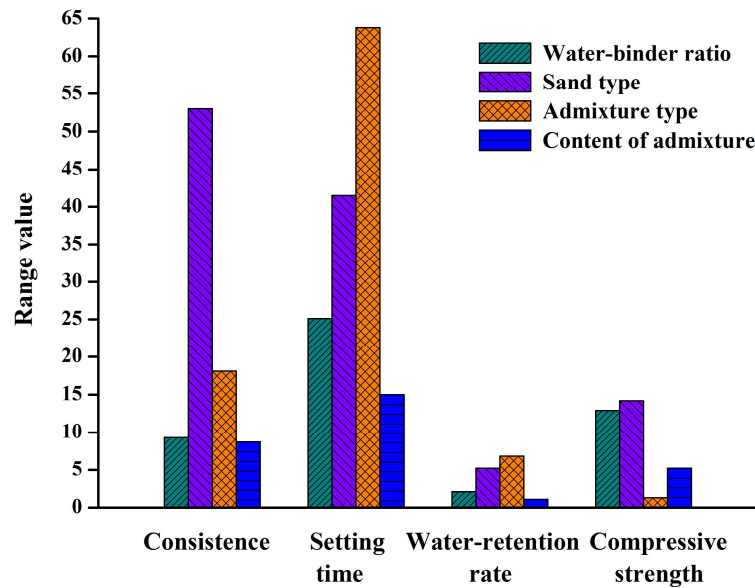


Figure 1 The range value of each factor

Water-binder ratio is related to each performance of premixed wet mortar, especially the compressive strength after hardening, though the range value is not the highest. The higher water-binder ratio, the more water can be adsorbed by fine aggregate and binding materials, resulting in lubricating interfaces. Thus the mortar has a better fluidity, larger consistence and longer setting time. On the contrary, mortar bleeding will happen if the water-binder ratio is too high, which also degrades the water-retention rate and long-term strength. Generally, the higher water-binder ratio can be chosen if the strength meets the requirements.

Sand type is a key factor, especially for consistence and compressive strength. The grain size distribution, fineness modulus and silt content of sand have a great influence on the workability of premixed wet mortar. Table 5 shows that the mortar using ISS (level b) has worse consistence and compressive strength. This is caused by different properties of sands. Compared with ISS, there is a certain amount of limestone on the surfaces of MMS and MS as well as a better grain size distribution, resulting in better workability of premixed wet mortar. Previously research<sup>[4]</sup> shows that the fineness modulus of sand has close relation to the performance of premixed wet mortar. A fineness modulus of 1.8-2.3 will be best for the integrated performance. Compressive strength of mortar will be degraded if the fineness modulus of sand is too small. When the fineness modulus of sand is too large, mortar has poor fluidity and water-retention rate because of the large amount of coarse particles. MS (60% MMS and 40% FRS) has a fineness modulus of 2.4, thus it is a better choice for premixed wet mortar.

Admixture type is also a key factor. The reducing free water consumed by cement hydration and the nucleation and growth of the hydration products lead to coagulation of cement particles. This is the main reason for poor fluidity and consistence<sup>[5]</sup>. Admixture plays an important role on prolonging mortar setting and hardening time. Most mortar admixtures are polymers, which contain large amount of groups that can be easily adsorbed by cement particles. Such kind of admixtures restrain the cement hydration effectively, and show great retarded and thickening effects<sup>[6]</sup>. Figure 1 indicates

that admixture type greatly affects the setting time of mortar. From the range analysis results shown in table 5, the mortar using admixture Y<sub>2</sub> (level b) has an average setting time of 5.5 hours, which is far shorter than 24 hours. Fortunately, admixture Y<sub>1</sub> and Y<sub>3</sub> meet the requirement. Especially for Y<sub>1</sub>, containing two independent components, it may adjust the performance of mortar flexibly.

Content of admixture has an significant influence on water-retention rate and compressive strength of premixed wet mortar. The retarded components of admixture dramatically prolong the initial and final setting time, resulting in a minimum loss of consistence and largest water-retention rate<sup>[7]</sup>. From this perspective, a large content of admixture is favorable. However, redundant admixture may delay the setting and hardening of cement, leading to a degraded compressive strength. According to the results of experiments, level b is the suitable dosage.

## Summary

(1) The range analysis indicates that the optimum parameter for each property of premixed wet mortar is as follows:

Consistence: B<sub>a</sub>C<sub>a</sub>A<sub>b</sub>D<sub>b</sub>,  
 Setting time: C<sub>a</sub>B<sub>c</sub>A<sub>a</sub>D<sub>b</sub>,  
 Water-retention rate: C<sub>c</sub>B<sub>c</sub>D<sub>c</sub>A<sub>b</sub>,  
 Compressive strength: B<sub>a</sub>A<sub>c</sub>D<sub>a</sub>C<sub>c</sub>

(2) Water-binder ratio affects greatly compressive strength. Large water-binder ratio leads to large consistence and long setting time, while poor water-retention rate and compressive strength. Large water-binder ratio can't be used unless the strength of mortar meets the requirement.

(3) Sand type plays an important role on the performance of premixed wet mortar. Mortar using MSS shows better compressive strength, but has a short setting time and low water-retention rate. Mortar using ISS shows poor integrated performance. Mortar using MS with a fineness modulus of 2.4 owns better workability and strength.

(4) The type and content of admixture mainly affect the consistence, setting time and water-retention rate. Admixture contains water reducing and retarded components may reduce water consumption, improve consistence and water-retention rate, and prolong setting time. However, large dosage of admixture is disadvantageous to the compressive strength. Thus small dosage is favorable if the workability of premixed wet mortar can be guaranteed.

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