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Research Article

Mechanical Properties of Modified Plastering Mortar Based on the Mesh Number of Manufactured Quartz Sand and Additives

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Abstract

Plastering mortar plays a protective role for building surface. Its mechanical properties are influenced by different factors. To improve the mechanical properties and solve the problems of mortar cracking and falling, this study proposed a method of studying the change in mechanical properties in accordance with the mesh number of quartz sand. The optimal mesh number of quartz sand was selected by measuring the water–cement ratio and consistency of fresh mortar, the compressive and flexural strength, and the water absorption rate of specimen. On the basis of the mesh number, an orthogonal test was designed using silica fume, calcium sulphoaluminate expansion agent, and polycarboxylate superplasticizer. The performance changes caused by the mesh number of quartz sand and the dosage of additives were analyzed, and plastering mortar with good mechanical properties was determined. Results demonstrate that the key to modification is to strengthen hydration reaction and compactness because cement mortar is porous and brittle. The mechanical properties of plastering mortar decrease with the increase in quartz sand mesh, and the effect is the best when 60–80 mesh quartz sand is used. When the additives are used for modification, the best effect can be obtained when mixing 3% silica fume, 5% calcium sulphoaluminate expansion agent, and 0.5% polycarboxylate superplasticizer. In this case, the compressive strength of the plastering mortar increases by about 22.8% and the water absorption decreases by about 2.4% compared with that before modification. The conclusions obtained in this study can provide an important reference for the modified application of plastering mortar.

Keywords: Mesh number of manufactured quartz sand, Additives, Plastering mortar, Modification study, Mechanical property

1. Introduction

As an essential part of cement mortar, sand substantially influences its performance. In consideration of reproducibility and convenient use, replacement of natural river sand with machine-made sand will be an inevitable choice in the civil engineering industry [1]. Quartz sand has the advantages of high temperature resistance, corrosion resistance, high insulation, and low thermal expansion coefficient. With excellent particle inclusion and physical and chemical stability, it can be used as mortar aggregate. Cement mortar has been widely used in plastering, bonding, constructing, and repairing buildings. It can connect materials and transfer stress [2-5]. As a common kind of cement mortar, plastering mortar is generally used on building surface to protect the overall structure. Therefore, plastering mortar should have good mechanical properties to ensure that it will not crack or fall off during long-term use.

However, mortar is a heterogeneous brittle material with porous structure. It has the characteristics of high brittleness, porosity, and water absorption in the hydration process of cement. Its poor mechanical properties after curing have a negative influence on the service effect and life. Thus, studying the modification of plastering mortar is of great practical significance and economic benefit. Scholars have conducted numerous studies on plastering mortar [6-8], but they have focused on the modification application of plastering mortar in special scenes. Problems remain in the basic mechanical properties and durability of plastering mortar. Therefore, how to improve the mechanical properties while ensuring the working performance of plastering mortar is an urgent problem to be solved.

This study combines experimental study with theoretical analysis and fully considers the influence of mesh number change on mechanical properties when machine-made quartz sand is used as mortar aggregate. As for modification additives, silica fume, calcium sulphoaluminate expansion agent, and polycarboxylate superplasticizer are reasonably selected to design orthogonal tests to study the changes in test data caused by different dosages. Aggregate and admixture are discussed separately to improve the mechanical properties of plastering mortar effectively, expecting to provide a reference for the popularization and modification of plastering mortar.

2. State of the art

Plastering mortar has attracted much attention because of its wide use in engineering. Gomes [9] analyzed the performance of plastering mortar by using cellulose pulp waste and found that adding a certain proportion of waste could improve the mechanical performance of plastering mortar. Cellulose pulp waste was recognized as a beneficial component in admixture, but few kinds of pulp waste were considered in the

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experiment. Spycha [10,11] studied the effects of lime and cellulose ether on plastering mortar, as well as the influence of different types of cement on plastering mortar with cellulose ether. The proper proportion of lime and cellulose ether could ensure the application performance of mortar, and the water retention of mortar was closely related to cellulose ether rather than cement type. Kheradmand [12] employed three kinds of phase change materials to prepare plastering mortar. Numerical simulation was implemented to study the change in thermal performance. Plastering mortar had excellent temperature regulation ability, but its action mechanism was not explained. Detphan [13] analyzed the influence of Portland cement containing fly ash, expanded perlite, and plasticizer on the performance of masonry and plastering mortar. The author suggested that the mixture with expanded perlite should be used for indoor plastering and the mixture with fly ash and plasticizer should be used for outdoor plastering to solve the cracking problem of masonry and mortar. Andres [14] discussed green plastering mortar based on natural materials, such as clay and wheat straw, and proved the feasibility of using natural organic materials to prepare new building materials with similar characteristics to traditional materials. Marcus [15] recycled cathode ray tube glass as a substitute for natural fine aggregate in plastering mortar. The results showed that the mortar had good chemical stability, and the lead content could meet the use requirements. However, the durability was not discussed. Sathiparan [16] discussed the influence of coconut shell fiber on the strength and durability of cement lime plaster mortar. The test results demonstrated that the residual strength and toughness after cracking were improved with the increase in coconut shell fiber content, but the feasibility in actual situation was not studied. Molnar [17] prepared an environment-friendly finishing mortar by using marble powder instead of mortar aggregate. The results showed that the compressive strength and bonding strength were the highest when marble powder replaced 25% of aggregate.

Tu [18] prepared plastering mortar with different thicknesses by using vitrified microbeads as aggregate and observed the dewing time in a constant temperature difference environment. The heat insulation and capillary water absorption of the mortar could prolong the dewing time, and the effect increased with the mortar thickness. Cui [19,20] studied different properties of plastering mortar with magnesium slag–lignin fiber composite. The magnesium slag and lignin fiber could inhibit the drying shrinkage of the mortar. Specifically, the magnesium slag could enhance the mechanical strength, while the lignin fiber could improve the water retention of the mortar. Wu [21] explored the influence of additive content on the performance of plastering thermal insulation mortar by using an orthogonal test method. The results showed that a proper amount of additive could improve the compressive strength of the mortar and decrease the dry apparent density. Zheng [22] analyzed the influence of additives on the properties of machine-made sand plastering mortar and found that reasonable compounding of several additives could guarantee high water retention rate, compressive strength, and construction performance of the mortar. Gao [23] studied the effects of water–binder ratio and water-reducing agent content on the physical properties, mechanical properties, and water resistance of modified phosphogypsum plastering mortar. Low water–binder ratio and dosage of water reducer could improve the mechanical properties and water resistance. Liu [24] tested the influence of three types of fibers on plastering mortar-infilled walls and found that plastering mortar with an appropriate amount of fibers could considerably improve the shear strength of masonry. Cao [25] studied the frost resistance of wet-mixed mortar with recycled sand and machine-made sand as aggregates. The results showed that the recycled sand had higher water absorption than the manufactured sand and remarkably influenced the frost resistance of the mortar. Ren [26] set five fly ash addition ratios to improve the performance of mortar. When the addition ratio was 25%, the fluidity of mortar reached the maximum value, and other properties were kept at a high level.

The above results focused on the reasonable content and action mechanism of different materials in plastering mortar. However, the study of the mixed use of different additives, especially of the mesh number of plastering mortar aggregate, is scarce. In this study, the water–cement ratio, consistency, compressive and flexural strength, and water absorption rate of plastering mortar were measured by combining experimental study with theoretical analysis and using relevant equipment and experimental schemes. The performance changes caused by the mesh number of quartz sand and the amount of admixture were discussed. The coupling relationship between admixture and mechanical properties was established, which provided the basis for the current optimization and later modification of plastering mortar.

The remainder of this study is organized as follows: Section 3 explains the test materials, equipment, and scheme in detail and constructs the test part. Section 4 summarizes the data obtained from the parallel test of sand mesh and the orthogonal test of additive modification and selects the best through chart comparison and theoretical analysis. Lastly, Section 5 summarizes this study and draws relevant conclusions.

3. Methodology

3.1 Main test materials

Ordinary Portland cement (P.O 42.5) shall be uniformly selected during the test. Manufactured quartz sand with different mesh numbers is shown in Fig. 1.

Fig. 1. Manufactured quartz sand with different mesh numbers

Silica fume with a SiO_2 content of 98% and a 28-day total activity of 105 is shown in Fig. 2. A calcium sulphoaluminate expansion agent with specific gravity of 2.8–3.0 and a 7-day limited expansion rate in water ≥ 0.025% is shown in Fig. 3. Mother liquor of LSJ-1 polycarboxylate superplasticizer with a solid content of 40%, a water-reducing rate ≥ 25%, and a gas content ≤ 3% is given in Fig. 4.

Fig. 2. Silica fume

Fig. 3. Calcium sulphoaluminate expansion agent

Fig. 4. Polycarboxylate superplasticizer

3.2 Main test equipment

A constant-load cement flexural and compressive testing machine with a maximum load of 300 kN and a calculation accuracy of 0.1 MPa is shown in Fig. 5.

Fig. 5. Bending and compression testing machine

A digital mortar consistency meter with a maximum range of rack of 150 mm and an accuracy of 1 mm is shown in Fig. 6. An electrothermal blast oven with a working temperature of 10 °C–300 °C and an accuracy of 1 °C is shown in Fig. 7.

Fig. 6. Mortar consistency meter

Fig. 7. Constant-temperature drying oven

3.3 Main test scheme

According to Chinese national standard JGJ/T 220-2010, the common consistency of plastering mortar should be 70±5. The cement–sand ratio is 1:2.5, so that the water–cement ratio of the mortar can be reasonably determined within the consistency range. After the consistency measurement, fresh mortar was used to prepare a set of three 40 mm×40 mm×160 mm cuboid mortar specimens, as shown in Fig. 8. After the prepared mortar specimens were demolded and numbered, cured specimens to the required age in a curing room with constant temperature and humidity (temperature: 23 ℃, relative humidity: 50%) to test the compressive and flexural strength. The optimal quartz sand mesh number was determined in accordance with the comprehensive analysis of the test results. Fig. 9 shows the mortar specimen curing room.

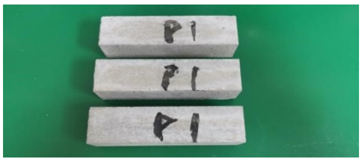


Fig. 8. Mortar specimen

Fig. 9. Mortar specimen curing room

After the optimum sand mesh number was determined in the above test, the cement–sand and water–cement ratios were fixed, and the appropriate admixture and dosage were selected. The effect of using additives in cement base materials is not linear. Low dosage of additives has no obvious or no effect, whereas high dosage destroys the original hydration reaction, resulting in negative effects and high cost. After reasonable investigation and design, the dosage of modified materials (percentage of cement mass) was as follows: the silica fume was 1%, 2%, 3%, and 4%; the calcium sulphoaluminate expansion agent was 2%, 3%, 4%, and 5%; and the polycarboxylate superplasticizer was 0.4%, 0.5%, 0.6%, and 0.7%.

There were 16 groups of orthogonal tests with 3 factors and 4 levels, as shown in Table 2. The specimen was prepared and cured, and the compressive strength, flexural strength, and water absorption rate of the plastering mortar specimen were measured after 28 days. The test results were analyzed, and a group of test proportions with the optimal performance after modification was selected. The methods used in the test process were as follows:

(1) Mortar consistency test method

Before the test, the status of the instrument was checked to ensure its normal use, and the sliding rod was wiped with lubricating oil to make it slide freely. The fresh mortar was placed in the slurry container wiped with a wet cloth, and the mortar surface was 10 mm below the rim of the container. The tamping rod was inserted 25 times from the center to the edge, and the container was gently shaken to smooth the mortar surface. The container was placed on the tester base. The tip of the test cone was slid to the mortar surface, and the brake screw was tightened to make the lower end of the rack measuring rod contact the upper end of the sliding rod. The instrument display was reset to zero. The brake screw was opened, and the time was recorded. The screw was tightened after 10 s, and the lower end of the rack measuring rod contacted with the upper end of the sliding rod again. The meter reading was read and accurate to 1 mm, which was the consistency value of fresh mortar. The arithmetic mean of two test results of mortar in the same plate was regarded as the standard measured value. When the difference between the two test values was greater than 10 mm, a new sample should be used for test.

(2) Test methods for the compressive and flexural strength of mortar specimens

After standing at room temperature, the mortar specimens with no moisture on the surface were placed in an automatic flexural and compressive testing machine. The flexural strength was measured first. During the test, the specimens were broken at the middle part. The data of a set of three specimens were taken and averaged as the test result. The compressive strength of six broken specimens was measured, and the average of six test results was regarded as the compressive strength value of mortar specimens. In the test, the results of flexural and compressive strength of the specimens should be accurate to 0.1 MPa.

(3) Test method for water absorption of mortar specimen

The mortar specimen was cured for 28 days and dried in a constant-temperature drying oven at 105 ℃ for 48 h. The specimen was weighed and recorded. Afterward, the specimen was completely soaked in a water tank at a temperature of 20 ℃ for 48 h. The specimen surface was wiped. The specimen was weighed and recorded. The water absorption rate of the mortar was calculated in accordance with the following formula.

$$W_X = \frac{m_1 - m_0}{m_0} \quad (1)$$

where: W_X —Mortar water absorption (%);

m_1 —Mass of specimen after water absorption (g);

m_0 —Mass of dried specimen (g);

In the test, the average of three specimens was regarded as the water absorption rate of the mortar, which was accurate to 0.1%.

4. Result Analysis and Discussion

4.1 Analysis of sand mesh number test results

In accordance with the above test scheme, parallel test of sand mesh number was performed. The relevant test proportioning and test results are given in Table 1.

Table 1. Proportioning and results of sand mesh number test

Mesh number	Water–cement ratio	Consistency	Compressive strength			Flexural strength		
		mm	7 d/MPa	14 d/MPa	28 d/MPa	7 d/MPa	14 d/MPa	28 d/MPa
40–60	0.55	67	29.8	35.9	40.9	4.3	4.7	5.1
60–80	0.60	75	26.9	33.0	41.2	4.2	4.8	5.3
80–100	0.70	77	16.2	22.3	33.7	3.6	4.0	4.2
100–120	0.75	72	12.7	17.1	26.2	3.0	3.4	3.5

4.1.1 Analysis of the mesh number and water cement ratio of quartz sand

The relationship between mesh number and water–cement ratio is presented in Fig. 10. When the consistency is controlled in a reasonable range, the water–cement ratio of 40–60 mesh quartz sand is the minimum, and that of 100–120 mesh quartz sand is the maximum. The water–cement ratio of mortar increases nonlinearly with the increase in mesh number. This is because the larger the mesh number is, the smaller the particle size and the larger the specific surface area will be; that is, the larger the total area per unit mass of quartz sand will be. To guarantee the suitable construction consistency and good workability of mortar, more cement paste is needed to coat and wet quartz sand particles; that is, more mixing water participates in the reaction, and the water–cement ratio becomes larger.

4.1.2 Analysis of compressive and flexural strength

In the hydration reaction of cement, various calcified compounds in cement particles mix with appropriate amount of water to form plastic slurry, which gradually coagulates and hardens into hard solid. Given their good inclusiveness, aggregate and other bulk materials are integrated into a whole, thus enhancing the properties . According to the above analysis, the water–cement ratio increases with the increase in mesh number. The excess mixing water is stored in the slurry after hydration reaction with cement particles. In the process of rapid hardening at the final setting time, a large number of pores or cavities are formed, which seriously damages the compactness of the specimen. A hollow state is formed, which is convenient for water and gas storage, thus decreasing the overall elastic modulus of the cured mortar specimen. Moreover, the corresponding mechanical properties are damaged, and the mortar cannot meet the use requirements. The relationship between mesh number and compressive and flexural strength is shown in Fig. 11.

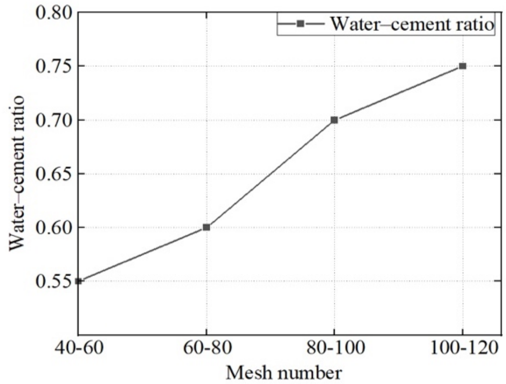
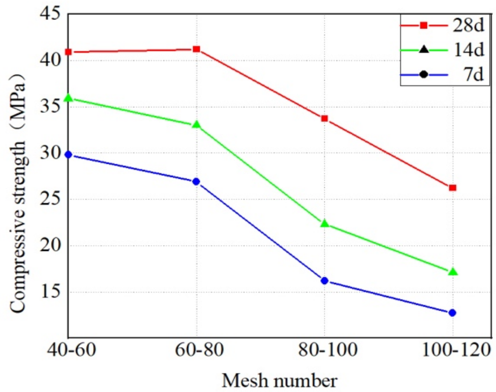
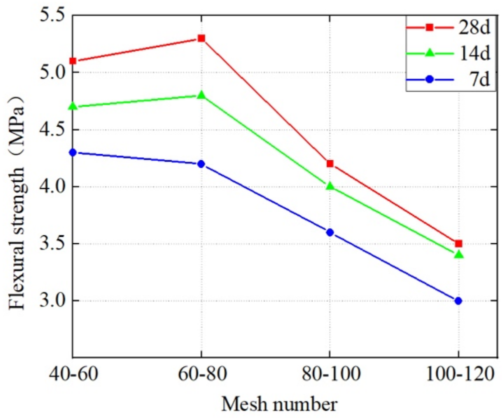


Fig. 10. Relationship between mesh number and water–cement ratio



(a) Compressive strength



(b) Flexural strength

Fig. 11. Relationship between mesh number and compressive and flexural strength

As shown in Fig. 11(a), the change law of the compressive strength of specimens with different sand mesh numbers is the same at 7 and 14 days; that is, the compressive strength decreases with the increase in mesh numbers. However, on the 28th day, the compressive strength first increases slightly with the change in mesh number and then decreases again, reaching the maximum at 60–80 mesh. As for the flexural strength, mortar specimens with different meshes still keep the abovementioned law at 7 days; that is, the strength decreases with the increase in mesh number. But at 14 and 28 days, the strength first increases, then decreases, reaching the highest at 60–80 mesh. From the above water–cement ratio and mechanical properties, 60–80 mesh manufactured quartz sand can be selected as the aggregate of modified plaster mortar.

4.2 Analysis of modification test results

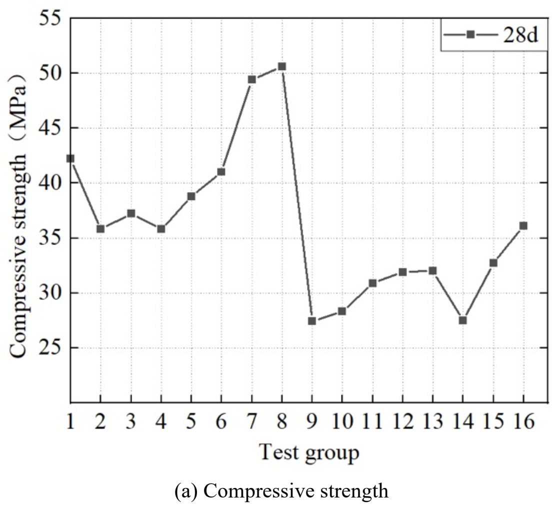
Owing to the water absorption effect of mortar pores, ordinary cement mortar has poor flexibility and is likely to crack, which is different from concrete that has enough coarse aggregate to enhance mechanical properties. Therefore, the modification of cement mortar is necessary to study. At present, three ways can be applied to improve the performance of mortar: organic polymers participate in the hydration reaction of cement; fine particles, such as inorganic mineral powder or metal powder, fill the pores of cement-based materials; and highly pozzolanic active materials generate relevant hydrates to improve the internal structure and compactness. Silica fume has the latter two characteristics, and it is suitable for modification of cement mortar. The expansion agent can react in cement and cause slight volume expansion to compensate for the shrinkage caused by subsequent curing. The hydrate (ettringite) produced by a calcium sulphoaluminate expansion agent has the advantages of stable period, controllable efficiency, low alkalinity, and no interference with hydration reaction. Moreover, the compressive and flexural strength of cement-based materials is closely related to the water–cement ratio [27]. The molecular structure of a carboxyl graft copolymer of polycarboxylate superplasticizer can disperse cement particles and reduce the amount of mixing water without affecting fluidity and workability. The compactness and strength of cement-based materials are enhanced. After the appropriate admixture and dosage were determined, an orthogonal test was designed, and the properties of each group were tested. The results are given in Table 2.

Table 2. Proportioning and results of modification test

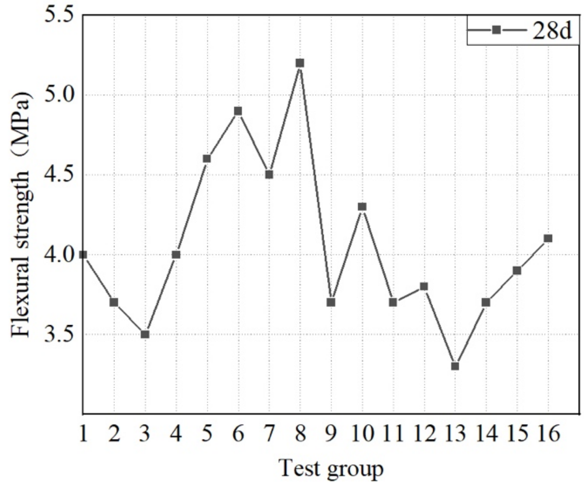
Groups	Silica fume	Expansion agent	Water reducing agent	Compressive strength	Flexural strength	Water absorption
	%	%	%	28 d/MPa	28 d/MPa	28 d/%
Blank	-	-	-	41.2	5.3	10.1
1	1	2	0.4	42.2	4.0	9.4
2	2	3	0.4	35.8	3.7	10.0
3	3	4	0.4	37.2	3.5	8.8
4	4	5	0.4	35.8	4.0	9.7
5	2	2	0.5	38.8	4.6	9.7
6	1	3	0.5	41.0	4.9	8.2
7	4	4	0.5	49.4	4.5	8.0
8	3	5	0.5	50.6	5.2	7.7
9	3	2	0.6	27.4	3.7	8.3
10	4	3	0.6	28.3	4.3	8.7
11	1	4	0.6	30.9	3.7	8.1
12	2	5	0.6	31.9	3.8	8.4
13	4	2	0.7	32.0	3.3	7.7
14	3	3	0.7	27.5	3.7	8.0
15	2	4	0.7	32.7	3.9	7.8
16	1	5	0.7	36.1	4.1	7.8

4.2.1 Analysis of compressive and flexural strength

Fig. 12(a) demonstrates that the highest compressive strength in the orthogonal test is 50.6 MPa in the eighth group, which is about 22.8% higher than that in the blank group. There is a great difference in compressive strength between the eighth and ninth groups. This may be caused by the excessive addition of water-reducing agent according to the analysis of the test proportioning of adjacent groups. Excessive addition of a polycarboxylate superplasticizer, which can disperse cement particles, can cause segregation of cement gel particles and aggregates, thus destroying the hydration reaction process and causing great damage to the strength. Although the strength can be enhanced by other factors, the effect is limited. In terms of flexural strength, there is a decline to different degrees in each group compared with the blank group, which may be due to the secondary reaction of a large amount of silica fume and calcium hydroxide generated by cement hydration. As a result, the water consumption increases, and microcracks are generated at the interface between aggregate and gelled particles, thus affecting the flexural strength of mortar to some extent [28]. The flexural strength of the eighth group is 5.2 MPa, which decreases slightly and is almost the same as that of the blank group.



(a) Compressive strength



(b) Flexural strength

Fig. 12. Compressive strength and flexural strength of each component in orthogonal test

4.2.2 Analysis of water absorption

Air exists when cement is mixed with water, and additional materials generate trace gases in the hydration reaction, which cannot be completely discharged by vibration, thus forming pores and cavities in the curing process. Substantial water is stored in the pores, which will damage the overall structure of mortar with the increase in service life. Therefore, the water absorption rate of mortar specimens should be tested as an evaluation index. Mortar is a heterogeneous brittle material with porous structure. The low water absorption rate can reflect the compactness of mortar to a certain extent and ensure the service life of mortar in a wet environment, such as underground engineering, thereby minimizing the negative impact caused by the existence and migration of internal moisture. The water absorption of each group after curing for 28 days in the orthogonal test is shown in Fig. 13.

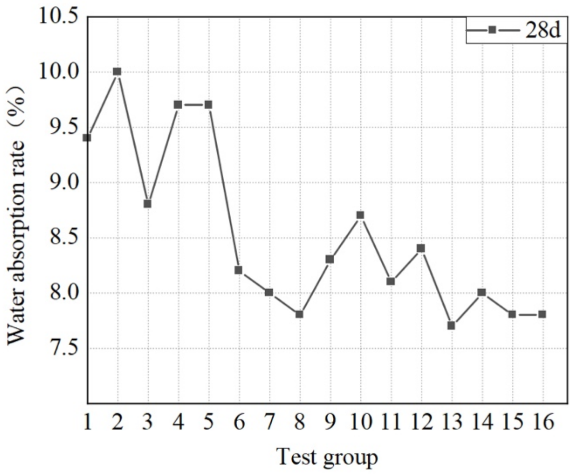


Fig. 13. Water absorption of each component in the orthogonal test

Fig. 13 depicts that the water absorption of each group in the orthogonal test is lower than that of the blank group. Hence, the selected materials affect the hydration reaction and compactness to a certain extent. The materials with some proportions may have a negative influence on mechanics, but they are conducive to reducing the water absorption rate of mortar. In the above test groups, the water absorption of the 8th and 13th groups reaches the lowest at 7.7%, which is about 2.4% lower than that of the blank group. In accordance with the previous analysis of compressive and flexural strength, the eighth group can be selected as the mixture ratio with the best mechanical property in the orthogonal test. Based on 60–80 mesh manufactured quartz sand, mixing silica fume with 3% cement mass, calcium sulphoaluminate expansion agent with 5% cement mass, and polycarboxylate superplasticizer with 0.5% cement mass is appropriate.

5. Conclusions

To improve the performance of plastering mortar, the influences of aggregate mesh number and admixture on mechanical properties were demonstrated. On the basis of the mesh number of manufactured quartz sand, three kinds of additives were mixed. The water–cement ratio, consistency, compressive and flexural strength, and water absorption rate of specimens were measured and analyzed through experimental study and theoretical analysis. Finally, the following conclusions were drawn:

(1) Plastering mortar has attracted much attention because of its wide application in engineering. It can be modified to be applied in some special occasions. It is a rigid material, and the excellent mechanical properties should be the basis of research and popularization. In consideration of the porous and brittle characteristics of cement mortar, it is the key to studying how to select materials reasonably to enhance its hydration reaction and compactness.

(2) Through a parallel test method, combined with the requirements of construction specifications, the consistency, water–cement ratio, and compressive and flexural strength of plaster mortar were comprehensively analyzed. The appropriate sand mesh number of plaster mortar was set to 60–80 mesh. The plastering mortar has not only good mechanical properties but also relatively stable performance in later stage because of the characteristics of quartz sand.

(3) Suitable materials and dosage were selected to modify the basic mortar to improve the hydration reaction and internal structure. Sixteen groups of orthogonal tests were designed. The results show that the mechanical properties are the best when silica fume with 3% cement mass, calcium sulphoaluminate expansion agent with 5% cement mass, and polycarboxylate superplasticizer with 0.5% cement mass are mixed. The flexural strength of cement mortar changes minimally compared with that without admixture. The compressive strength increases by about 22.8%, and the water absorption decreases by about 2.4%.

From the experimental data and mechanism analysis, this study discussed the influences of sand mesh and additives on the mechanical properties of plastering mortar and established the relationship between dosage and properties. It has a certain reference for exploring the modification of plastering mortar. Owing to the lack of actual data about durability monitoring, future study will combine mechanical properties with practical effects to understand the law of the mechanical properties of plastering mortar more accurately.

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