Hindawi
Advances in Materials Science and Engineering
Volume 2019, Article ID 5978089, 10 pages
https://doi.org/10.1155/2019/5978089

Research Article

Effects of Chemical Admixtures on the Working and Mechanical Properties of Ordinary Dry-Mixed Mortar

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Received 17 July 2018; Accepted 3 January 2019; Published 22 January 2019

Academic Editor: Charles C. Sorrell

The effects of hydroxypropyl methyl cellulose ether, starch ether, bentonite, and redispersion emulsoid powder on the working and mechanical properties of fresh dry-mixed mortar were studied. The results show that hydroxypropyl methyl cellulose ether has the greatest impact on the consistency and water retention of ordinary dry-mixed mortar and that redispersion emulsoid powder reduces the water action and starch ether has essentially no effect on water retention. It also shows that the time of mortar condensation when mixed with hydroxypropyl methyl cellulose ether is the longest, followed by redispersion emulsoid powder and bentonite. Starch ether can slightly, but not obviously, extend the setting time of cement mortar. Hydroxypropyl methyl cellulose ether has the greatest impact on the mechanical properties of ordinary dry-mixed mortar, followed by redispersion emulsoid powder, starch ether, and bentonite. As the water retention increases, the setting time of the mortar also increases. The use of water as a thickening material has a retarding effect on the mortar, increases the water-retention rate, and increases the retarding effect. Moreover, increasing the content of the chemical admixtures decreases the strength of cement mortar.

1. Introduction

The difference between the use of dry mortar and concrete as a structural material is not only the necessary strength but also the need for water retention, bonding, water proofing, crack resistance, impact resistance, anti-freeze-thaw, high-temperature endurance, thermal insulation, and other requirements. Thus, many types of admixtures, such as hydroxypropyl methyl cellulose ether, starch ether, bentonite, and redispersible latex powder, are added to dry mortar to improve its properties.

The effect of admixtures on dry mortar is a topic of interest for researchers [1–4]. Research results have indicated that the water-retention ability of dry mortar was significantly improved by the addition of hydroxypropyl methyl cellulose ether [2, 3]. Moreover, the consistency also increased [4, 5]. As starch ether was mixed into the dry mortar, the vertical degree decreased [6]. The bonding strength of dry mortar was enhanced substantially by the powder [7, 8]. Some additional admixtures can improve the working performance and mechanical behavior of dry mortar to other degrees [9, 10]. However, most of the current studies have focused on single chemical admixtures; thus, a comprehensive comparative study of the effects of various admixtures on the properties of dry-mixed mortar is needed. As the effects of ordinary dry mortar admixtures on the performance of mortar are determined, engineers and technicians can add chemical additives according to the process requirements.

This paper studies the influence of four types of admixtures that are hydroxypropyl methyl cellulose ether, starch ether, bentonite, and redispersible latex powder on the properties of dry-mixed mortar and analyzes their applicability in ordinary dry-mixed mortar and the relationship between the performances. It aims to improve the work and mechanical properties of dry-mixed mortar which is used as wall plastering, ground mortar, and special mortar. The investigation refers to Chinese standard JGJ70-2009, and the main tests performed include the consistency test, water-retention test, setting time test, and cubical compressive strength test.

2. Experimental Program

2.1. Materials. Ordinary Portland cement of 42.5 R grade and class II fly ash were utilized for the experiment, and natural river sand with a fineness modulus of 2.43 was used as the fine aggregate. Detailed parameters of the cement, sand, and fly ash are presented in Tables 1–3.

The admixtures selected for this investigation were hydroxypropyl methyl cellulose ether (60YT10000) produced by Shandong Teng Chemical Co., Ltd., starch ether produced by Longhu Technology (Beijing) Co., Ltd., redispersion emulsoid powder, and bentonite. The parameters of the admixtures satisfy the requirements of Chinese standards JG/T l64-2004, GB/T 29594-2013, and GB/T 20973-2007.

2.2. Test Design. In this experiment, different admixtures were utilized to investigate and analyze the properties of common dry-mixed mortar. The mix is shown in Table 4.

2.2.1. Consistency Test. In this test, the consistency of the fresh mortar is measured by using a mortar consistency meter according to the Chinese standard JGJ70-2009, as shown in Figure 1.

2.2.2. Water-Retention Test. The water-retention of the fresh mortar is measured by using a water-retention test instrument according to the Chinese standard JGJ70-2009, as shown in Figure 2.

The test procedure is illustrated as follows. (a) Weigh the bottom impervious sheet and the dry proof mass and 15 medium-speed qualitative filter papers. (b) Put the mortar mixture into the test mold after being inserted with a spatula for several times. As the mortar is slightly higher than the edge of the test mold, the excess surface should be removed at 45°, and the mortar is smoothed at a relatively flat angle in the opposite direction of the surface of the test mold. (c) Wipe out the mortar on the side of the test mold, and weigh the test mold, the bottom impervious sheet, and the mortar. (d) Cover the surface of the mortar with a metal filter, place 15 pieces of filter paper on the surface of the filter, and then, cover the surface of the filter paper with an upper impervious sheet, and press the upper impervious sheet with a weight of 2 kg. (e) After being placed for 2 minutes, the heavy object and the upper impervious sheet should be removed and the filter paper (excluding the filter) is taken out and weighed quickly. (f) Calculate the water content of the mortar according to the mix ratio of the mortar and the amount of water added.

2.2.3. Setting Time Test. The setting time of the fresh mortar is measured by using a setting time tester according to the Chinese standard JGJ70-2009, as shown in Figure 3.

The test procedure is illustrated as follows. (a) Put the prepared mortar into the container and shock compaction, and then, put it in the test condition of (20 ± 2)°C. (b) Place the container on the pressure gauge disc and adjust the measuring instrument. (c) Test the penetration resistance value with a penetration test needle with the cross-section area of 30 mm^2 to contact the surface of the mortar, and then, press the needle into the mortar vertically to a depth of 25 mm within 10 seconds slowly and uniformly. Therefore, record the meter value N_p every time as the penetration is made. (d) Under the test condition of (20 ± 2)°C, the actual penetration resistance value should be measured at 2 h after molding, and then measured every half hour. As the penetration resistance value reaches 0.3 MPa, it should be measured every 15 min until the penetration resistance value reaches 0.7 MPa.

Penetration resistance strength f_p can be achieved according to the following formula:

$$f_p = \frac{N_p}{A_p}, \quad (1)$$

where f_p is the penetration resistance strength with the unit of MPa, N_p is the static pressure at penetration depths up to 25 mm with the unit of N, and A_p is the cross-sectional area of the test needle with the value of 30 mm^2.

2.2.4. Compressive Strength. Mortar cube specimens with a dimension of 70.7 mm × 70.7 mm × 70.7 mm (length × width × height) are made for the compressive strength test, as shown in Figure 4. The 1.3 times of the average value of three specimens was taken as the compressive strength of the mortar (accurate to 0.1 Mpa). When the maximum or minimum of the three measured values has a difference from the intermediate value exceeding 15% of the intermediate value, the maximum value and the minimum value are rounded off together and the intermediate value is taken as the pressure strength. If the difference between the two measured values and the intermediate value both exceed 15% of the intermediate value, the test results are invalid.

Compressive strength $f_{m,cu}$ can be achieved according to the following formula:

$$f_{m,cu} = \frac{N_u}{A}, \quad (2)$$

where $f_{m,cu}$ is the compressive strength of the mortar cube specimen with the unit of MPa, N_u is the ultimate load with the unit of N, and A is the area of the cube specimen with the unit of mm^2.

3. Results and Discussion

3.1. Consistency Test. Different admixtures were mixed into the fresh dry mortar, and the influence on the consistency of the ordinary dry mortar was analyzed. The test results are shown in Figure 5.

When the water content of the dry mortar was 19% and the cellulose ether content was 0.03%, the consistency of the mortar was very small and the fluidity was extremely poor, as

Table 1: Main properties of cement.

Flexural strength (MPa)		Compressive strength (MPa)		Standard consistency of water consumption (%)	Initial setting time (h)	Final setting time (h)	Stability
3 d	28 d	3 d	28 d				
6.9	8.6	36.2	47.3	28.4	2.45	3.26	Qualified

Table 2: Main properties of sand.

Mud content (%)	Clay lump (%)	Fineness modulus	Apparent density (kg/m^3)	Loose density (kg/m^3)	Porosity (%)
1.05	0.15	2.43	2630	1500	44

Note. Mud content is the particle content of natural sand with nominal particle size less than 0.075 mm. Clay lump: the nominal particle size in natural sand is greater than 1.25 mm and the lump is cleaned with water, and the content of particles is smaller than 630 microns after hand pinching.

Table 3: Main properties of class II fly ash.

Performance index	National standard	Test results	Conclusion
Fineness (45 μm sieve) (%)	≤25	4.2	Qualified
Water content (%)	≤1.0	0.2	Qualified
Mobility ratio (%)	≤105	86	Qualified
Stability	–	–	Qualified

Table 4: Mix of ordinary dry-mixed mortar (percentage of powder).

Admixture	Cement (%)	Fly ash (%)	Sand (%)	Water (%)	Admixture volume (%)
Hydroxypropyl methyl cellulose ether	13.0	7.0	79.92~79.99	19	0.01%~0.08
Dispersible latex powder	13.0	7.0	78.0~79.95	19	0.5%~2.0
Starch ether	13.0	7.0	79.91~79.99	19	0.01%~0.09
Bentonite	13.0	7.0	74.0~79.0	19	1.0%~6.0

(a) (b)

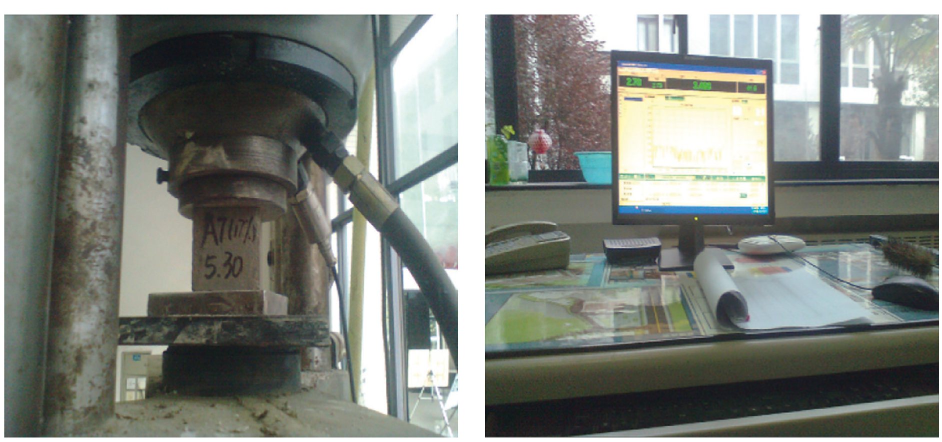
Figure 1: Consistency instrument.

shown in Figure 5(a). This characteristic is mainly due to the fact that cellulose ether is insoluble in water and only swells when a substituent is introduced into the molecular chain to destroy the hydrogen bonds. After the cellulose ether expands and the solution enters, it becomes water soluble and forms a highly viscous slurry suspension. As shown in Figure 5(b), an increase in the redispersible latex powder content improves the consistency and flowability of the mortar, indicating that the redispersible latex powder has a water-reducing effect. This effect is the result of the redispersible latex powder increasing the gas content of the mortar and thus lubricating the fresh mortar. Latex powder can provide protection from water when the colloid is dispersed and can improve the viscosity of the slurry and the cohesion of the construction mortar, thereby improving the workability. Starch ether has the most obvious effect on the early consistency of the mortar, as shown in Figure 5(c). Starch ether improves the consistency increase and fluidity

(a) (b)

Figure 2: Water-retention test instrument.

Figure 3: Setting time tester.



(a) (b)

Figure 4: The compressive strength test.

and prolongs the stirring time. Bentonite is the additive that is added in the largest amount. It is a rock composed of montmorillonite, and it is highly water absorbent and highly expandable after absorbing water. Bentonite can be dispersed into a gel-like and suspended state in an aqueous medium. Such a solution has a high degree of viscosity and a high adsorption capacity for water. Therefore, the thickening effect of bentonite is very good. When the bentonite content reaches 3%, the consistency of the mortar is very small and the fluidity is very poor, as shown in Figure 5(d). In summary, the cellulose ether content is the most important factor in the consistency of common dry mortars, followed

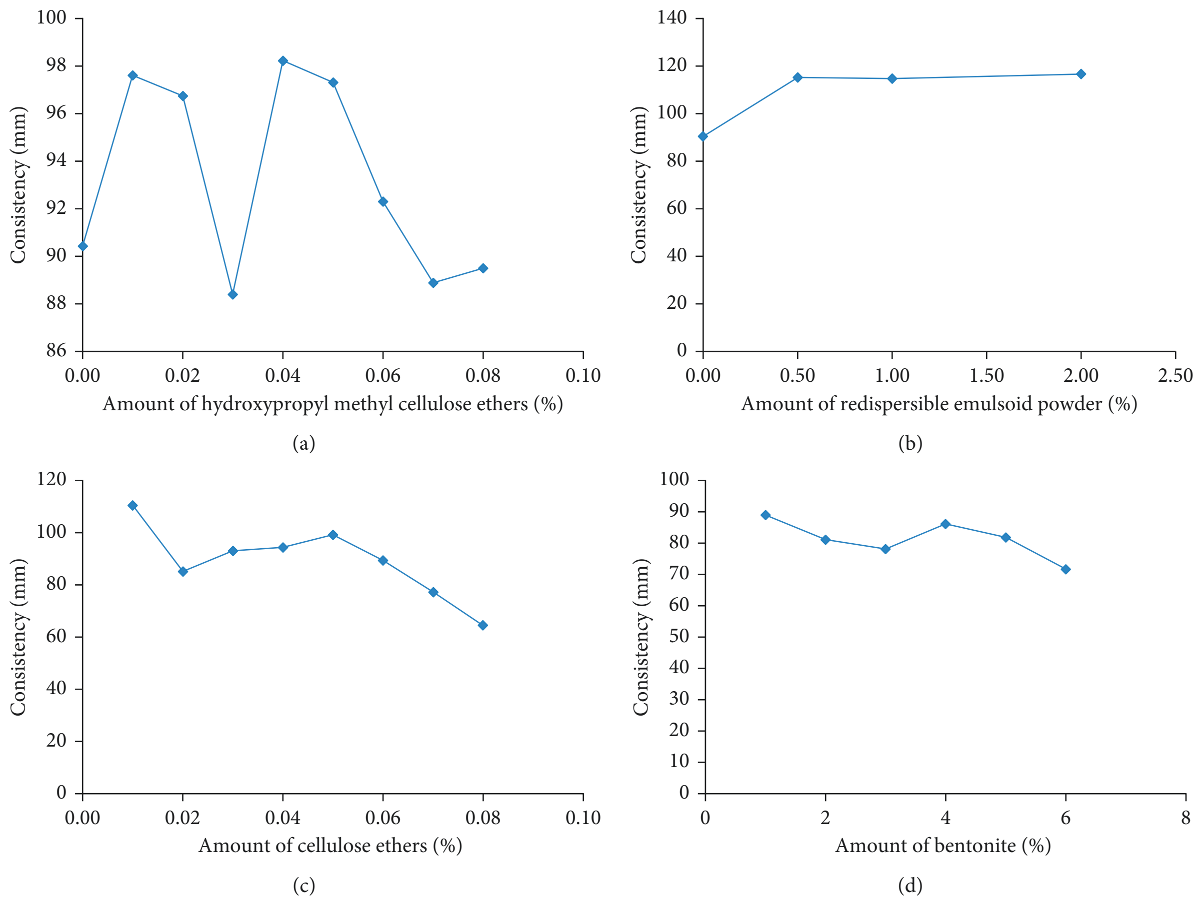


FIGURE 5: Influence of admixtures on the mortar consistency. (a) Hydroxypropyl methyl cellulose ethers. (b) Redispersion emulsoid powder. (c) Starch ethers. (d) Bentonite.

by the starch ether and bentonite content, while redispersion emulsoid powders have a water-reducing effect [10].

3.2. Water-Retention Test. Different admixtures were mixed into fresh dry mortar, and the influence on the water-retention rate of the ordinary dry mortar was analyzed. The test results are shown in Figure 6.

The standard for the construction mortar performance test method JGJ/T70-2009 stipulates that the mortar water-retention rate can be calculated according to the following formula:

$$W = \left[1 - \frac{m4 - m2}{\alpha \times (m3 - m1)}\right] \times 100, \quad (3)$$

where $m1$ is the weight of the impervious sheet and the dry proof mass, $m2$ is the weight of 15 medium-speed qualitative filter papers, $m3$ is the weight of the test mold, the bottom impervious sheet, and the mortar, and $m4$ is the weight of the weight of 15 medium-speed qualitative filter papers in the wet state, and α is the moisture content of mortar.

As shown in Figure 6(b), many microbubbles are formed due to the incorporation of cellulose ether into the cement mortar. These bubbles act like ball bearings, improving the workability of the fresh mortar. In hardening the mortar, the bubbles are retained to form pores that are independent of one another and act to block the pores to reduce the water absorption of the mortar. Therefore, the water retention of mortar increases with increasing hydroxypropyl methyl cellulose ether content. In addition, cellulose ethers have good water-retention capacity due to intermolecular forces (Van der Waals forces). When the content of cellulose ethers is 0.02%, the water-retention rate reaches 88%; when the content is 0.03%, the water-retention rate is 92%. These water-retention values exceed the national standard (≥88%).

As the content of redispersible latex powder increases, the water-retention rate of the mortar also increases because the added powder has a dispersing effect and results in substantial air entrainment in the mortar mixture. Therefore, its water reduction effect is strong. However, redispersible latex powder has a limited role in improving the water retention of mortar and enhancing its cohesiveness.

The water-retention effect of starch ether was not obvious. When the blending content increased from 0% to 0.02%, the water-retention rate of the mortar increased and then decreased with further increases in the blending amount. When the amount reached 0.06%, the water-retention rate of the mortar essentially did not change.

When the amount of bentonite is greater than 2%, the water-retention rate of the mortar reaches the national standard

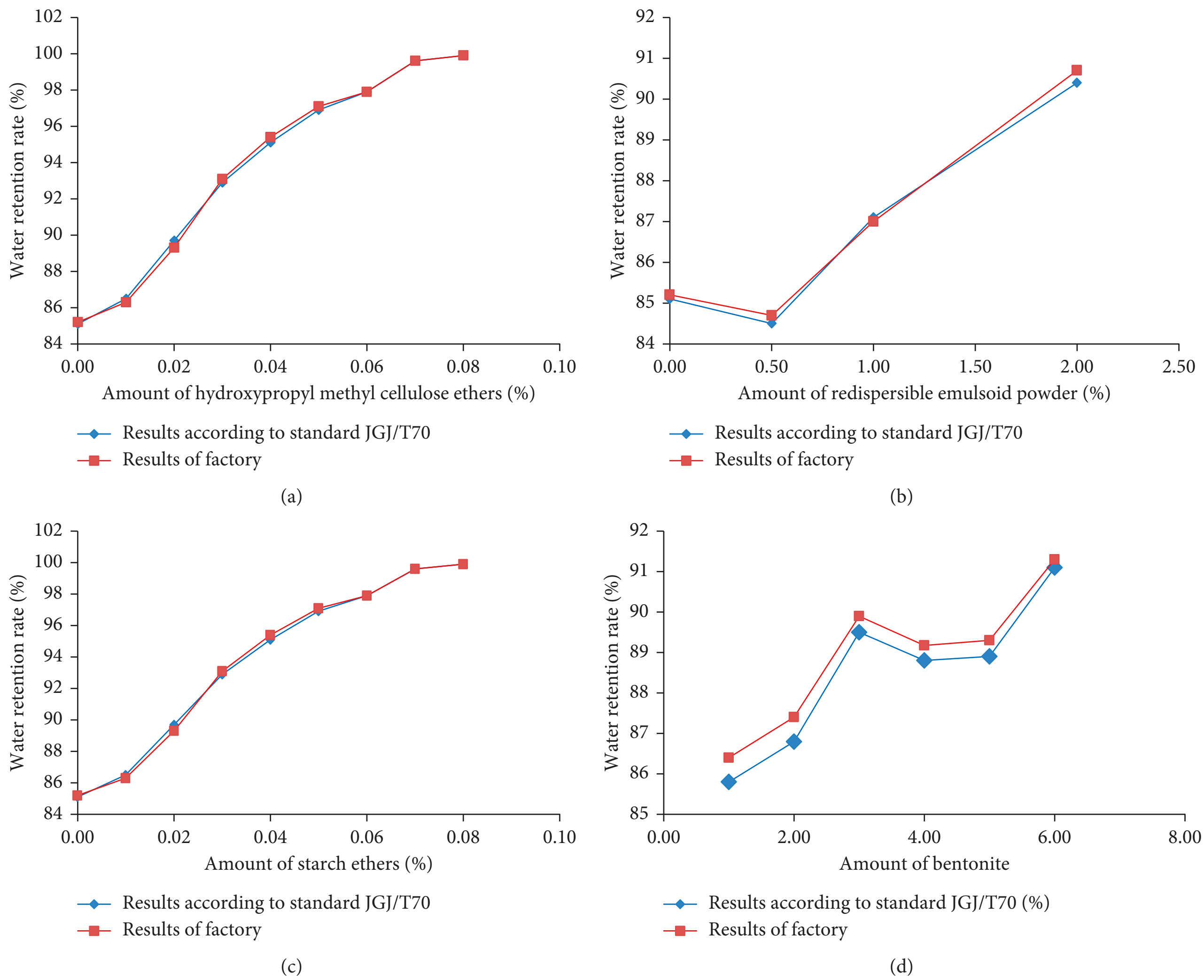


Figure 6: Influence of admixture on the mortar water-retention rate. (a) Hydroxypropyl methyl cellulose ethers. (b) Redispersion emulsoid powder. (c) Starch ethers. (d) Bentonite.

(≥88%). As the bentonite content increases, the water-retention rate of the mortar slowly increases. When the bentonite content was 6%, the water-retention rate of the mortar was 91.3%.

In summary, cellulose ether is the most important factor in the water retention of ordinary dry-mixed mortars, followed by redispersion emulsoid powder. Bentonite plays an important role in water retention, but starch ethers have virtually no water-retention effect.

3.3. Setting Time Test. The setting time periods of the experimental specimens are illustrated in Figures 7 and 8.

Different admixtures were mixed into the fresh ordinary dry mortar, and the effect on the setting time was analyzed. The test results show that when no admixture is incorporated, the setting time of the mortar increases slightly with increasing water consumption. As the admixture was incorporated, the setting time of mortar increased. Since the addition of cellulose ether has a strong effect on the hydration of cement, the coagulation time is the longest when cellulose ether is

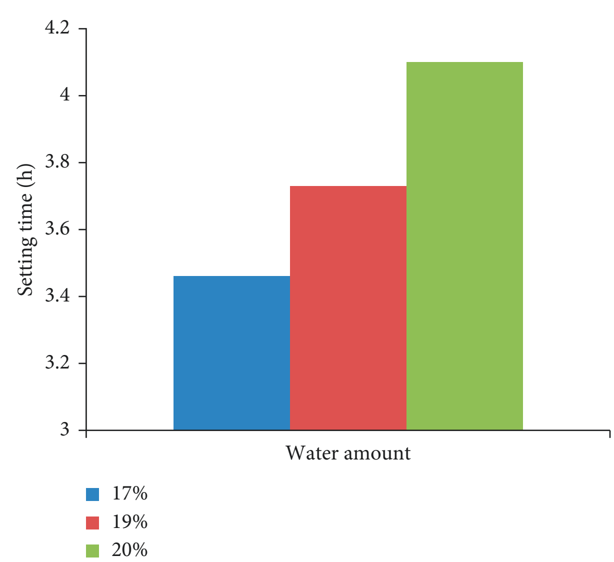


Figure 7: Influence of water amount on ordinary dry mortar setting time.

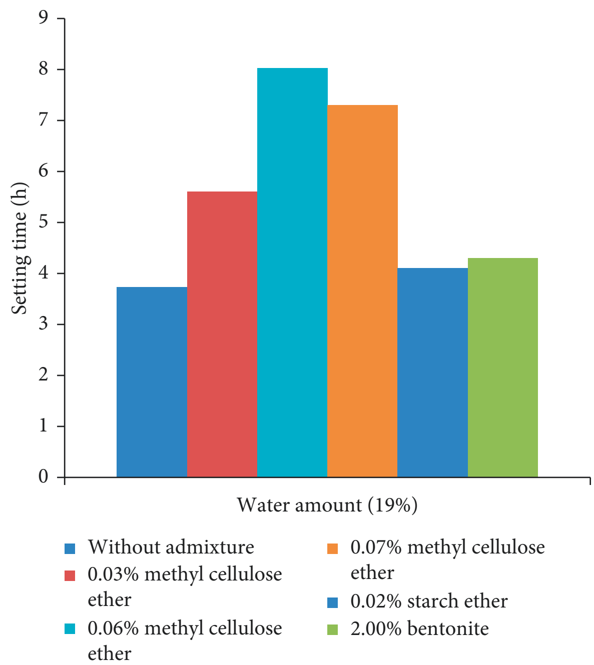


FIGURE 8: Influence of the different admixtures on ordinary dry mortar setting time.

incorporated, followed by redispersion emulsoid powder and bentonite. The incorporation of starch ether slightly, but not obviously, prolongs the setting time of the mortar.

3.4. Compressive Strength. The 28-day compressive strengths of the experimental specimens are shown in Figure 9.

Different admixtures were mixed into the fresh dry mortar, and the influence of the admixtures on the compressive strength was analyzed. The test results show that the addition of cellulose ether not only introduces a large number of bubbles but also influences the hydration of the cement. Cellulose ether has the greatest impact on the compressive strength of dry-mixed mortar, and the compressive strength of dry-mixed mortar containing cellulose ether decreases the most in 28 days. The reason that redispersion emulsoid powder affects the compressive strength of mortar is that excessive addition leads to the introduction of excessive bubbles, resulting in a decreasing trend in the compressive strength. The next greatest impact on the compressive strength is due to starch ethers, followed by bentonite. This result is closely related to the role of bentonite in cement mortar. The volume expansion of bentonite after water absorption can compensate for the drying shrinkage problem of cement stone and can reduce the occurrence of shrinkage cracks. The colloidal particles formed by clay particles can enhance the adhesion of cement paste, which fills in the pores and acts as a solid to increase the strength.

3.5. Relationship between the Water-Retention Rate and Condensation Time. The relationship between setting time and the change in water-retention rate is shown in Figure 10.

As the water-retention rate of the mortar increases, the setting time of the mortar also increases. The water-retaining thickening material has a retarding effect on the mortar. The greater the water-retention rate of the mortar, the more obvious the retarding effect. The period of time between the mixing of the dry-mixed mortar and the construction application is called the storage time. Consistency is a parameter that characterizes the construction performance of mortar. The consistency of mortar is reduced to varying degrees as the storage time increases. In the cement particles, the mineral components C_3A and C_3S react with water to form ettringite and C-S-H gels, thereby consuming a large amount of free water, reducing the fluidity of the cement slurry, and decreasing the consistency of the mortar. Simultaneously, the nucleation of the cement hydration product increases, which causes the agglomeration of cement particles, leading to a decrease in the fluidity of the cement slurry and a decrease in the consistency of the mortar [10]. A large number of tests showed that increasing the storage time reduces the consistency and fluidity of the mortar and deteriorates the mortar compactness, which affects the hardening properties of the mortar. The addition of water-retaining and thickening materials reduces the amount of free water in the dry-mixed mortar after the water is added, which results in a slower rate of hydration of the mineral components C_3A and C_3S, thus slowing the mortar.

3.6. Relationship between the Water-Retention Rate and Compressive Strength of Concrete. The relationships between the 28-day compressive strength of the specimens and the water-retention rate are illustrated in Figure 11.

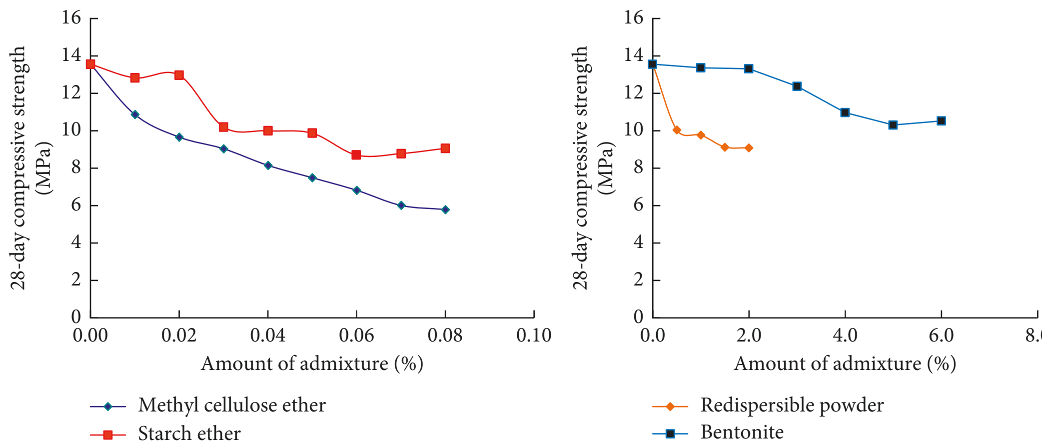


Figure 9: Relationship between the 28-day compressive strength of mortar and amount of admixture.

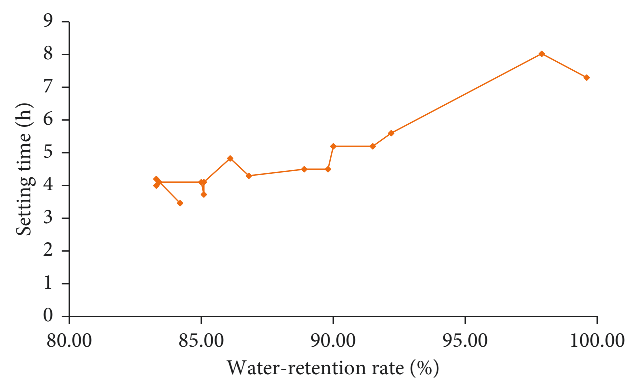


Figure 10: The relationship between setting time with change of water maintainability.

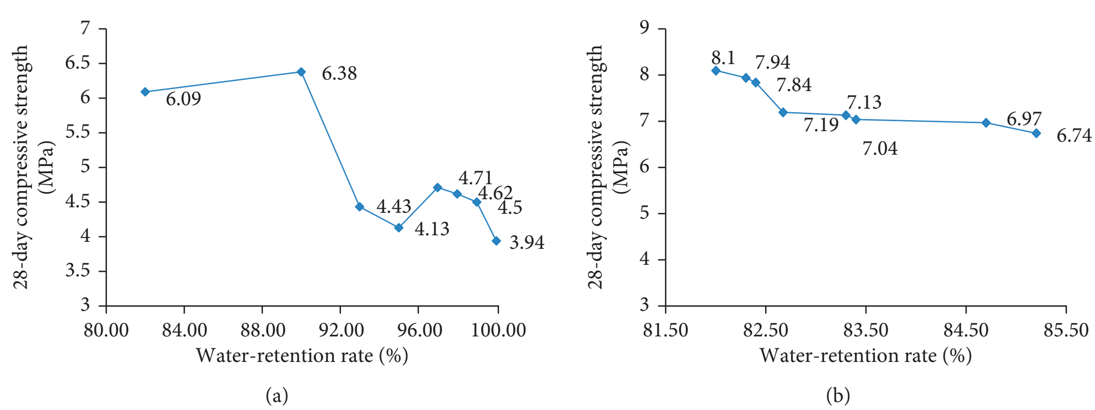
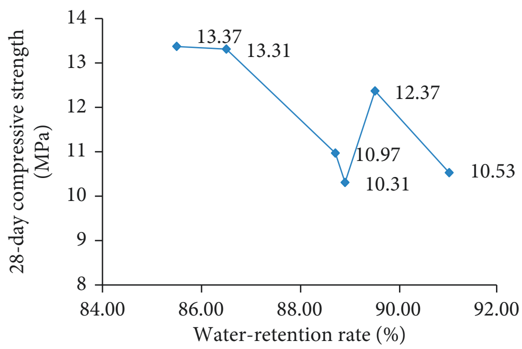
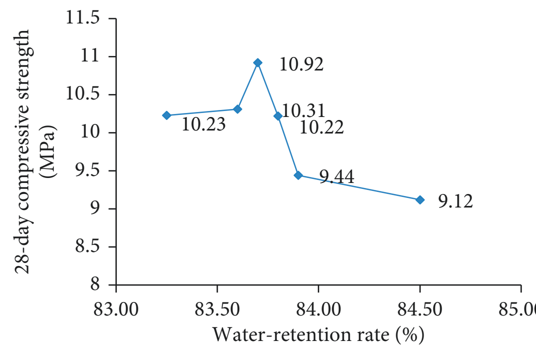


Figure 11: Continued.



(c)



(d)

Figure 11: Change of the 28-day compressive strength of mortar with the increase of water-retention rate. (a) With cellulose ether added. (b) With starch ethers added. (c) With bentonite added. (d) With redispersion emulsoid powder added.

As shown in Figure 11, the 28-day compressive strength of the mortar decreases with increasing mortar water retention. When the mortar is admixed with additives, the amount of soft polymer in the pores of the mortar increases, and these flexible polymers do not provide rigid support when the composite matrix is pressed, resulting in a decrease in the strength of the mortar. Some additives with methyl groups (such as cellulose ether and redispersion emulsoid powder) have a certain amount of bleed air. As the additive content increases, the bleed air effect gradually increases, the compactness of the mortar gradually decreases, and the strength decreases. The air-entraining effect of the admixture can improve the workability of the mortar, but it reduces its strength. Usually, for every 1% increase in gas content, the 28-day strength will decrease by 3% to 5%. However, the strength of the mortar does not steadily decrease with the addition of the admixture; there are some fluctuations, mainly because the bubbles caused by admixture incorporation have a negative effect on the development of mortar strength. However, these bubbles can improve the workability of mortar and reduce the water-cement ratio, resulting in an increase in strength. Therefore, as the admixture content increases, the strength of the mortar shows a decreasing trend.

4. Conclusion

Cellulose ether has the most obvious effects on the consistency, water-retention rate, and compressive strength of common dry mortar. Redispersion emulsoid powders have a water-reducing effect. Bentonite provides a degree of water retention, and starch ether has essentially no water-retention effect. The addition of admixtures can prolong the setting time of the mortar, and the longest setting time is observed when cellulose ether is added.

The setting time of the mortar is prolonged as the water-retention rate increases. Water-retaining and thickening materials have a retarding effect on the mortar, and the mortar 28-day compressive strength decreases with increasing mortar water-retention rate. The stronger the water-retention capacity of the mortar is, the lower the 28-day compressive strength.

Data Availability

All data generated or analyzed during this study are included in this published article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors gratefully acknowledge the financial support from the Fundamental Research Funds for the Central Universities (2017XKZD09). The experimental work described in this paper was conducted at the Jiangsu Key Laboratory of Environmental Impact and Structural Safety in Civil Engineering in the China University of Mining and Technology. Staff and students at the laboratory are greatly acknowledged for their help during the testing.

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