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Effect of Different Mineral Admixtures on the Dry Shrinkage and Mechanical Properties of Mortar

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Abstract: In this paper, the effects of four different mineral ginseng materials on the mechanical properties of mortar were studied, and the results showed that high territory, fly ash, and silica fume had an inhibitory effect on the drying shrinkage of mortar, and mineral powder increased the drying shrinkage of mortar. The high territory in the mineral admixture has the best effect on the inhibition of mortar drying shrinkage. The compressive strength and flexural strength of the mortar can be improved by adding a certain amount of mineral admixture, which increases the compressive strength by about 20%-40% and the flexural strength by about 20%-30% compared with the control group, and the improvement effect difference between different components is not large.

Keywords: Mineral admixtures; Dry shrinkage performance; Mechanical properties; Polymer mortar

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1. Introduction

Cement mortar, one of the most widely used building materials in construction, is considered to be the most economically practical material due to its low cost and wide application. However, with its widespread use, a series of performance defects have also been exposed, such as low bonding strength, high brittleness, significant shrinkage, and poor crack resistance [1–4]. Therefore, how to improve the performance of cement mortar has become a widely concerned issue. Many scholars at home and abroad have found that mineral admixtures can improve its working performance. Research by Zhou et al. showed that when the ratio of metakaolin to mineral powder is appropriate, the geopolymer has a denser structure and when the content of metakaolin is higher, the resulting geopolymer gel has stronger acid resistance [5]. Properly increasing the mineral powder can enhance the durability of the repair material by improving the density of the structure. Liu et al. found that the compressive strength of fly ash mortar with a large amount of silica fume increases and then decreases with the increase of silica fume content and the pattern of single mineral powder addition is similar to that of silica fume [6]. Both silica fume and mineral powder have a good strengthening effect on fly ash mortar with a large amount of addition. Therefore, this paper comprehensively studies the effects of four different mineral admixtures on the drying shrinkage performance and mechanical properties of cement mortar, aiming to provide a certain reference for the in-depth study of mortar performance improvement.

2. Overview of the trial

2.1. Mix design

Metakaolin (MK), fly ash (F), ore powder (Slag) and silica fume (SF) were used to replace 5%, 10%, 15% and 20% of cement in mass fractions. **Table 1** illustrates the fits.

Table 1. Mineral admixture mixture

Component	Cement/g	Sand/g	Water/ml	MK/g	F/g	Slag/g	SF/g	Water reducer/g
Control	500	1000	325	—	—	—	—	1
MK5	475	1000	325	25	—	—	—	1
MK10	450	1000	325	50	—	—	—	1
MK15	425	1000	325	75	—	—	—	1
MK20	400	1000	325	100	—	—	—	1
F5	475	1000	325	—	25	—	—	1
F10	450	1000	325	—	50	—	—	1
F15	425	1000	325	—	75	—	—	1
F20	400	1000	325	—	100	—	—	1
Slag5	475	1000	325	—	—	25	—	1
Slag10	450	1000	325	—	—	50	—	1
Slag15	425	1000	325	—	—	75	—	1
Slag20	400	1000	325	—	—	100	—	1
SF5	475	1000	325	—	—	—	25	1
SF10	450	1000	325	—	—	—	50	1
SF15	425	1000	325	—	—	—	75	1
SF20	400	1000	325	—	—	—	100	1

2.2. Test method

Dry shrinkage, flexural strength, and compressive strength: tested in accordance with JGJ/T 70-2009 "Test Method for Basic Properties of Construction Mortar", as shown in **Figure 1.**

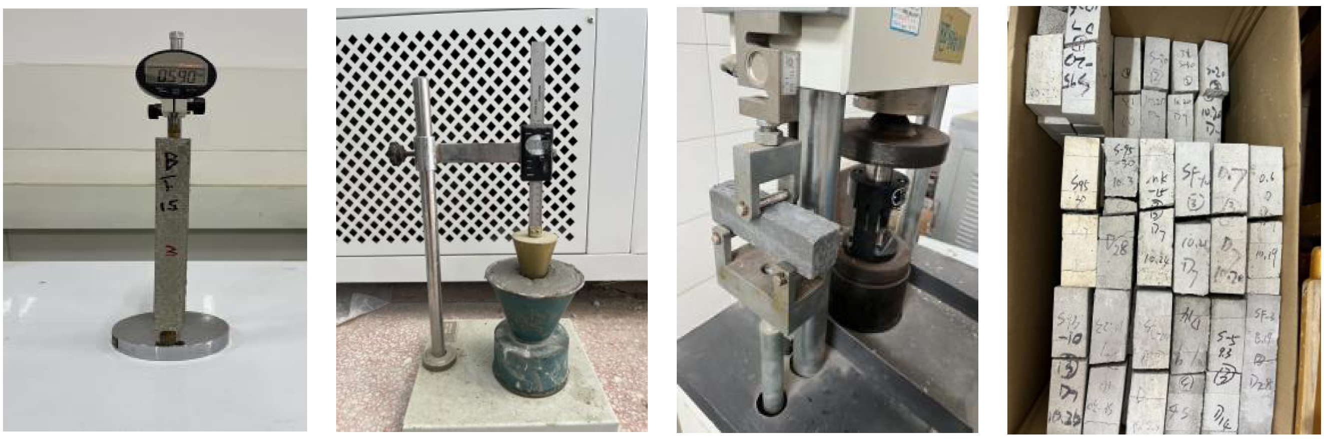

Figure 1. Test device and test process

3. Test results and analysis

3.1. Effect on the dry shrinkage properties of mortar

Mortar drying shrinkage refers to the volume shrinkage and deformation of cement mortar due to water loss in an environment with low relative humidity, referred to as dry shrinkage. Due to the lack of maintenance or insufficient maintenance in the early stage, the surface exuded water evaporates and is lost in the surrounding dry environment, resulting in surface drying, the appearance of surface dryness, the continuous diffusion and migration of internal moisture to the outer surface, and the reduction of internal moisture causes the phenomenon of drying and shrinkage [7]. Therefore, this chapter explores the effects of materials with different components and different dosages on the dry shrinkage of mortar and compares the improvement effects of fibers, mineral admixtures, and polymer emulsions on the dry shrinkage properties of mortars.

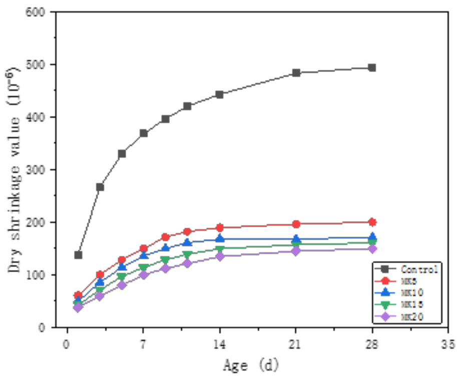

Figure 2. Effect of metakaolin on mortar drying

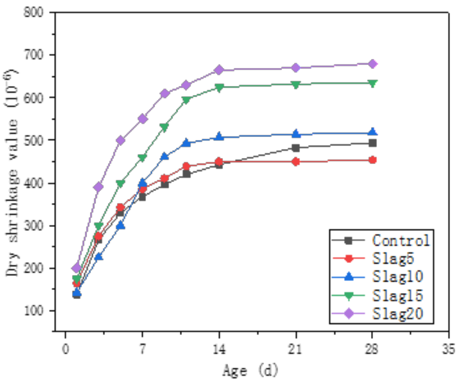

Figure 3. Effect of fly ash on mortar shrinkage

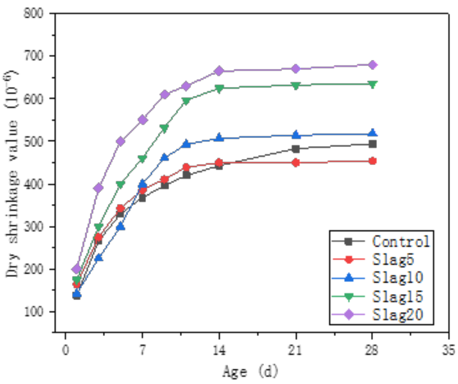

Figure 4. Effect of mineral powder on mortar dry shrinkage

Figure 2 shows the influence of metakaolin on the shrinkage and deformation of special mortar, and on the whole, a certain amount of high territory mixed with mortar has a certain inhibitory effect on the dry shrinkage of mortar. In the territory with high substitution rates of 5%, 10%, 15% and 20% of cement mass fraction, the dry shrinkage of mortar in 28 days was 200 × 10^{-6}, 171 × 10^{-6}, 161 × 10^{-6} and 150 × 10^{-6}, which were significantly lower than those in the control group (494 × 10^{-6}). This is because metakaolin can reduce the content of pores and capillaries in the mortar, and it has a large amount of active Al_2O_3, which promotes the formation of related products in the reaction and inhibits the drying shrinkage of the mortar.

Figure 3 is the influence of fly ash on the shrinkage and deformation of special mortar, on the whole, a certain amount of fly ash in the mortar has a certain inhibitory effect on the dry shrinkage of the mortar. Mixed with fly ash with 5%, 10%, 15% and 20% of the cement mass fraction substitution rate, the dry shrinkage of the mortar in 28 days was 239 × 10^{-6}, 207 × 10^{-6}, 178 × 10^{-6} and 162 × 10^{-6}, which were significantly lower than those in the control group (494 × 10^{-6}). On one hand, the amount of cement is reduced after being mixed with fly ash, the hydration rate of fly ash is slow, and the unreacted fly ash plays a role in stabilizing and inhibiting the deformation of the slurry [8]. On the other hand, the fine particles of fly ash are evenly distributed in the matrix phase of the cement slurry, just like fine aggregates. It binds well to the gel, which reduces the dry shrinkage of the mortar [9].

Figure 4 shows the influence of mineral powder on the shrinkage and deformation of special mortar. On the whole, a certain amount of mineral powder in the mortar has a certain inhibitory effect on the dry shrinkage of the mortar. The 28-day dry shrinkage of the mortar was 454 × 10^{-6}, 518 × 10^{-6}, 636 × 10^{-6}, and 682 × 10^{-6}, which were significantly higher than those in the control group (494 × 10^{-6}). As the amount of mineral powder increases, the proportion of cement in the cementitious material decreases. In the early stages, the hydration products generated by the mineral powder are relatively limited. With the evaporation and loss of water, the porosity of the slurry increases, making it more prone to significant shrinkage and deformation.

Figure 5 shows the influence of silica fume on the shrinkage and deformation of mortar. The dry shrinkage of the mortar has a certain inhibitory effect. The 28-day dry shrinkage of the mortar was 186 × 10^{-6}, 204 × 10^{-6}, 236 × 10^{-6}, and 279 × 10^{-6}, which were significantly lower than that of the control group (494×10^{-6}). This is mainly due to the small particle size of silica fume, which can reduce the content of pores and capillary pores while increasing the content of gel pores. At the same time, the drying shrinkage of mortar is usually caused by water loss from fine capillary pores and large gel pores, so silica fume can increase the difficulty of water migration and reduce the drying shrinkage of cement mortar [10].

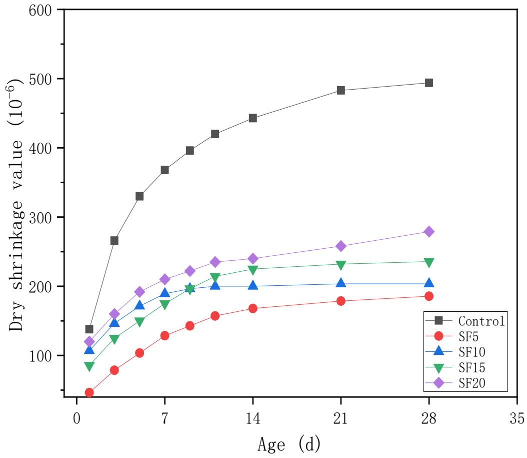

Figure 5. Effect of silica fume on mortar dry shrinkage

3.2. Effect on the compressive strength and flexural strength of the mortar

In this subsection, the effects of different amounts of metakaolin (MK), fly ash (F), mineral powder (Slag), and silica fume (SF) on the compressive strength and flexural strength of the mortar are studied. The compressive strength and flexural strength of metakaolin monomix with different cement substitution rates (5%, 10%, 15%, 20%) for special mortar are shown in **Figure 6.**

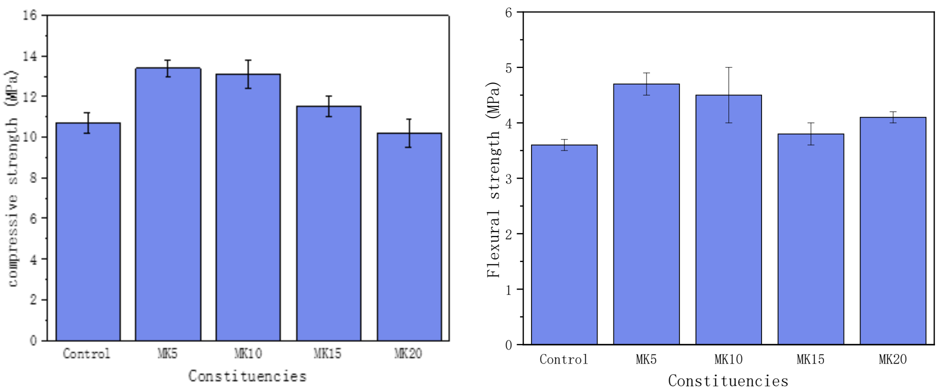

Figure 6. The compressive strength of different amounts of kaolin on mortar.

The left side of **Figure 6** illustrates the effect of metakaolin on the compressive strength of special mortar. It can be observed that after incorporating metakaolin, the compressive strength at 7 days initially increases and then decreases. When the cement substitution rate is 5%, the compressive strength reaches its peak at 13.4 MPa, representing a 25.2% increase compared to the control group. Additionally, the compressive strength of MK10 and MK15 increases by 22.4% and 7.5%, respectively, compared to the control group. However, when the metakaolin substitution rate reaches 20%, the strength begins to decline. The compressive strength of the mortar was reduced to 10.2MPa, which was 4.7% lower than that of the control group.

The right side of **Figure 6** illustrates the effect of metakaolin on the flexural strength of special mortar. It can be observed that as the metakaolin substitution rate increases, the flexural strength initially decreases and then rises. When the cement substitution rate is 5%, the flexural strength reaches its peak at 4.7 MPa, representing a 30.6% increase compared to the control group. Additionally, the flexural strength of the MK10, MK15, and MK20 groups increases by 25%, 5.6%, and 13.9%, respectively, compared to the control group. As the amount of metakaolin increases, the total heat of hydration of cement decreases. Additionally, since the particle size of metakaolin is larger than that of cement particles, the total porosity of the cementitious material increases with higher metakaolin content. This increase in porosity leads to a reduction in compressive strength, as observed in the MK20 group [11].

The compressive strength and flexural strength of fly ash with different cement substitution rates (5%, 10%, 15%, 20%) for special mortar are shown in **Figure 7**.

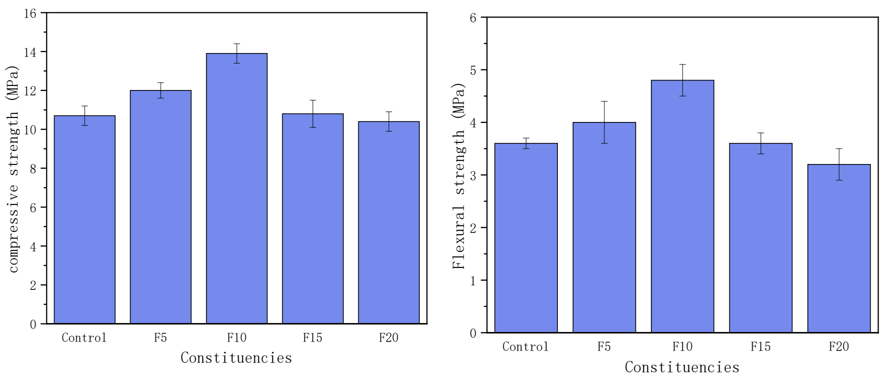

Figure 7. Effect of different amounts of fly ash on the compressive strength of special mortar.

The left side of **Figure 7** illustrates the impact of fly ash on the compressive strength of special mortar. As shown in the figure, after the addition of fly ash, the 7-day compressive strength initially increases and then decreases. The compressive strength reaches its peak at a cement substitution rate of 10%, achieving a maximum value of 13.9 MPa, with an increase of 29.9% compared to the control group. Additionally, the 7-day compressive strength of the F5 and F15 components is 12 MPa and 10.8 MPa, respectively. However, as the fly ash substitution rate increases to 20%, the compressive strength continues to decline. The compressive strength of the mortar was reduced to 10.4MPa, which was 2.8% lower than that of the control group.

The right side of the figure illustrates the effect of fly ash on the flexural strength of special mortar. As shown, with an increasing fly ash substitution rate, the flexural strength initially rises and then declines. The flexural strength reaches its peak at a 10% cement substitution rate, achieving a maximum value of 4.8 MPa, with an increase of 33.3% compared to the control group. However, as the fly ash substitution rate increases to 20%, the flexural strength of the F20 component reaches its lowest value. The cement content in the cementitious material was lower than that of the control group (11.1), resulting in a reduced amount of cement in the mixture. Additionally, the content of calcium silicate generated by the high-alkali hydration reaction decreased, leading to a weakened secondary hydration effect of fly ash [12]. The compressive strength and flexural strength of mineral powder with different cement substitution rates (5%, 10%, 15%, 20%) for special mortar are shown in **Figure 8**.

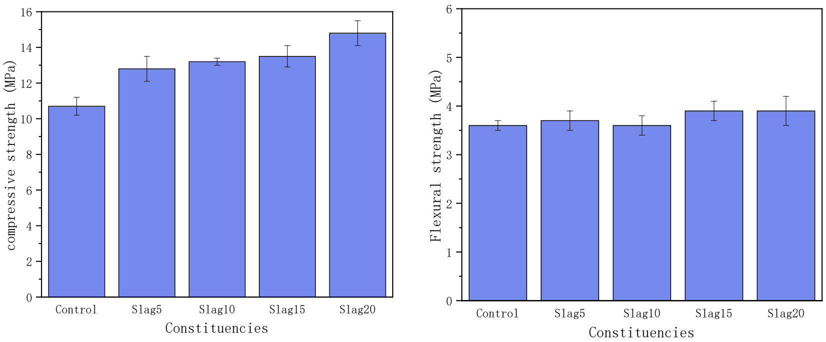

Figure 8. Effect of different amounts of mineral powder on the compressive strength of special mortar.

The left of **Figure 8** is the influence of mineral powder on the compressive strength of special mortar. The figure shows that after the addition of mineral powder, the 7-day compressive strength exhibits an overall trend. When mixed with cement at substitution rates of 5%, 10%, 15%, and 20%, the compressive strength of the Slag5, Slag10, Slag15, and Slag20 components reached 12.8 MPa, 13.2 MPa, 13.5 MPa, and 14.8 MPa, respectively. Notably, the compressive strength of the Slag20 component increased by 38.3% compared to the control group. The right side of the figure illustrates the influence of mineral powder on the flexural strength of special mortar. As shown in the figure, with the increase in the substitution rate of mineral powder, the flexural strength of special mortar exhibits a gradual upward trend. The maximum flexural strength of 3.9 MPa is achieved when the mineral powder is mixed at a 20% cement substitution rate.

In **Figure 9**, the compressive strength and flexural strength of fly ash with different cement substitution rates (5%, 10%, 15%, 20%) for special mortar are shown.

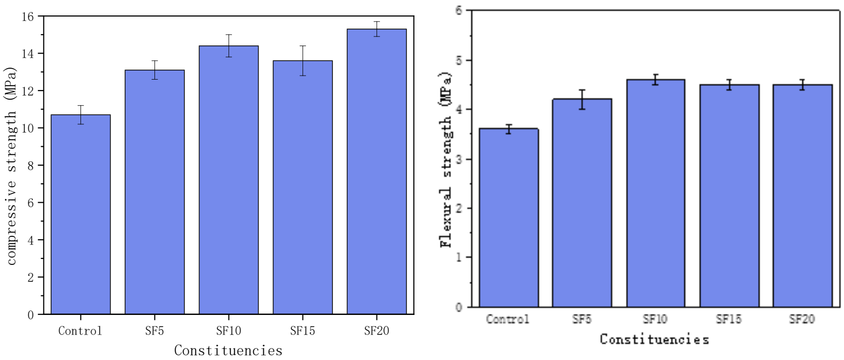

Figure 9. Effect of different amounts of silica fume on the compressive strength of special mortar.

The left side of **Figure 9** illustrates the influence of silica fume on the compressive strength of special mortar. As shown in the figure, after the incorporation of silica fume, the compressive strength at the 7-day age exhibits an overall increasing trend. The maximum compressive strength of 15.3 MPa is achieved when the silica fume substitution rate reaches 20%, representing a 43% increase compared to the control group. Additionally, the 7-day compressive strengths of SF5, SF10, and SF15 components are 13.1 MPa, 14.4 MPa, and 13.6 MPa, respectively. The right of the figure shows the effect of silica fume on the flexural strength of the special mortar. It can be seen that with the increase of silica fume substitution rate, the flexural strength first shows a slight increase and is higher than that of the control group, while the highest flexural strength of the SF10 group is 4.6MPa, which is 27.8% higher than that of the control group.

4. Conclusion

To summarize, the high territory, fly ash, and silica fume have an inhibition effect on the drying shrinkage of mortar, while mineral powder will increase the drying shrinkage of mortar. The high territory in the mineral admixture has the best effect on the inhibition of mortar drying shrinkage. The 28-day dry shrinkage value of metakaolin with a content of 20% decreased by about 69% compared with the control group. The compressive strength and flexural strength of the mortar can be improved by adding a certain amount of mineral admixture, which increases the compressive strength by about 20%–40% and the flexural strength by about 20%–30% compared with the control group, though the improvement effect difference between different components is not large.

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