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# Experimental Study on Preparation of Dry-Mixed Mortar from Coal Gangue

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**Abstract:** In this experiment, the influence of coal gangue as the admixture on the performance of dry-mixed mortar was studied, and the results were analyzed by XRD and SEM. The effects of different ways of crushing, particle size distribution, coal gangue, cement, admixture, and water content on the water retention, consistency, and 7 d compressive strength of dry-mixed mortar were investigated. The results show that the optimum content of hammer crushing of coal gangue through 3 mm sieve and cement is 83% and 17% of the total mass (*W/W*), respectively, the admixture content of 1# compound is 0.2 g/kg, and the amount of water is in the range of 194~200 mL/kg. At this time, the consistency can reach 91.5 mm, the water retention rate can reach 92.11%, and the 7 d compressive strength can reach 10.6 MPa, which meets the requirements of dry-mixed mortar for ordinary plastering and masonry mortar (GB-T 25181-2019).

**Keywords:** coal gangue; dry-mixed mortar; consistency; water retention; compressive strength

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## 1. Introduction

Dry-mixed mortar refers to a kind of granular or powdery material that is physically mixed with dried and screened aggregates (such as quartz sand), inorganic cementations materials (such as cement), and additives (such as polymers) in a certain proportion, is transported to the construction site in bags or bulk, and can be directly used after mixing with water [1]. It plays the role of bonding, lining, protection, and decoration with thin layer in the construction industry and is widely used in construction and decoration engineering [2–4].

In recent years, with the development of national environmental protection needs, there has been an emergency in local buildings. Most of China's standards, policies and local laws have been combined to actively promote dry-mixed mortar to support the development of dry-mixed mortar. With the determination of national political goals, environmental market opportunities will be further increased, and an attractive and vast industrial blue ocean will emerge [5–7].

The large output of gangue and the large accumulation of gangue mountains are common problems in coal mines around the world, and many researchers have paid attention to the utilization of gangue [8,9]. China's gangue has been applied to energy, construction, chemical, agriculture, and other industries and has made some progress. At present, we should improve the existing technology based on the original, increase the research and development of the efficient utilization technology of gangue, and realize the high value-added utilization of gangue. Zhang et al. [10] replaced cement with a part of gangue ground to fine ash to prepare concrete, and the results showed that when the replacement rate was approximately 15%, the properties of the concrete were almost the same as those of pure cement concrete. Chen et al. [11] reviewed the current research progress of domestic and foreign scholars on the mechanical properties and durability of gangue, pumice, and ceramic light aggregate concrete, obtained different types of hard bone materials, particle size, shape, and substitution rate and introduced the effects of the mixture and aggregate activation on the mechanical properties and durability of concrete [12–14]. However, the preparation of dry-mixed mortar from coal gangue and its application have not been reported.

This project mainly studies the ratio of coal gangue replacing river sand to prepare dry-mix mortar. Ordinary dry-mixed mortar is mainly divided into three categories: (1) Masonry mortar, which meets the masonry standard, examines water retention and compressive strength, and is used for wall masonry. (2) Plastering mortar, which examines the consistency and viscosity requirements, is used for the mortar of building wall decoration and plastering. (3) Floor mortar, which examines the requirements of water retention and compressive strength, is similar to masonry mortar and is mainly used for pouring the ground [15,16]. Therefore, consistency, water retention, and compressive strength tests were carried out according to JGJ/T 70-2009 in this experiment. The results obtained by the test are analyzed, and the influencing factors of consistency, water retention, and compressive strength are discussed. In this experiment, the dry-mixed mortar prepared from cement, gangue, and admixtures (active agents) can be widely used in masonry, plastering, ordinary waterproofing, caulking, and ground repair. At the same time, to make greater use of the raw material of gangue, this work mainly verifies the maximum dosage of gangue and the best ratio of other materials. This work can make full use of industrial waste and gangue tailings that have a huge negative impact on the environment, produce dry-mixed mortar with broad market prospects, and meet the requirements of ordinary plaster mortar and masonry mortar in the ready-mixed mortar standard GB/T25181-2019, which can not only solve the problem of raw material depletion but also produce economic benefits, environmental benefits, and ecological benefits.

## 2. Experiment

### *2.1. Experimental Raw Materials*

The gangue used in this project comes from Gushi County, Henan Province, and the number is GS. As shown in Table 1, the chemical composition of Gushi coal gangue is mainly $SiO_2$ and $Al_2O_3$, the sum of which accounts for 73.65%, and there are some small amounts of $Fe_2O_3$, CaO, MgO, $K_2O$, etc., and also contains a very small amount of metal elements, such as titanium, strontium, copper, zirconium and so on.

**Table 1.** Chemical composition analysis of coal gangue (w/%).

| Number | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | $P_2O_5$ |
|---|---|---|---|---|---|---|---|---|---|
| GS | 47.46 | 26.19 | 1.24 | 0.08 | 0.69 | 1.90 | 0.25 | 0.40 | 0.05 |
| number | $TiO_2$ | NiO | CuO | $ZrO_2$ | SrO | $Cr_2O_3$ | $CeO_2$ | I.L | Σ |
| GS | 1.09 | 0.01 | 0.01 | 0.03 | 0.01 | 0.03 | 0.03 | 20.52 | 99.99 |

The cement used in this project is the Xinshan Cement P·O42.5 Ordinary Portland cement. The basic physical and mechanical properties of cement are shown in Table 2. The chemical composition of cement is shown in Table 3.

**Table 2.** Physical and mechanical properties of cement.

| Cement | Standard Consistency% | Condensation Time/Min | | Flexural Strength/MPa | | Compressive Strength/MPa | |
|---|---|---|---|---|---|---|---|
| | | Initial Condensation | Final Condensation | 3d | 28d | 3d | 28d |
| P·O42.5 | 27.4 | 186 | 230 | 6.1 | 8.6 | 26.4 | 49.6 |

**Table 3.** Chemical composition of cement (w/%).

| Cement | $SiO_2$ | CaO | $Al_2O_3$ | $Fe_2O_3$ | MgO | $SO_3$ | $R_2O$ | Loss |
|---|---|---|---|---|---|---|---|---|
| P·O42.5 | 23.45 | 60.24 | 5.37 | 2.81 | 2.56 | 2.86 | 0.37 | 2.34 |

Admxture 1#: Hubei Jinzhu New Material Technology Co., LTD., Wu Han, China,
Admxture 2#: Henan Xingwei Intelligent Building Material Technology Co., LTD., Gushi, China.
Function: adjust the consistency and water retention of dry-mixed mortar.

*2.2. Experimental Instruments and Equipment*

Drying chamber (JJC101 type electric heat drum air drying box, Nantong Jiacheng Instrument Co., Ltd., Jiangsu, China), hotplate (DWK Electric ace Controller, Jiangsu Yixing Dingshan Electrical Appliance Protection Factory), ball mill (YXQM-2L Planetary Ball Mill, Changsha Miqi Instrument and Equipment Co., Ltd.), jaw crusher (EP-2, Hebi Haotian Electric Co., Ltd.), hammer crusher (through 3 mm sieve), and KER-PK180 × 150, Zhenjiang Kerui Sample Equipment Co., Ltd.) were used in this work.

Cement anti-bending and compression all-in-one machine (YAM-300D, Zhejiang Yiwu Instrument and Equipment Co., Ltd.), shock type standard vibrating screen machine digital mortar consistency meter (ZBSX-92A, Wuxi Xiyi Building materials Instrument Factory), digital display mortar consistency meter (SC-145, Tianjin Zhenhui Construction Instrument Co., Ltd.), standard consistency meter (TD505-WK1, Wuxi Zhongke Building Materials Instrument Co., Ltd), cement sand mixer(JJ-5 Wuxi Xiyi Building materials Instrument Factory), cement purification slurry mixer (NJ-160A, Shanghai Luda Experimental Instrument Co., Ltd.), cement concrete constant temperature and humidity standard maintenance box (SHBY-40B, Zhejiang Jixiang Instrument Co., Ltd.), direct-coupled air compressors (1HP, Nancheng Thomas Electromechanical Technology Co., Ltd.), concrete, cement mortar plastic test film (70.7 × 70.7 × 70.7 mm, Cangzhou Lanbiao Construction Instrument Factory), X-ray Analyzer (XRD, DX-2700B, Dandong Fangyuan Instrument Co., Ltd.), and cold field emission scanning electron microscope (JSM-6700F, Japanese electronics) were used in the experiments.

*2.3. Experimental Process*

2.3.1. Experimental Flowchart for Preparing Dry-Mix Mortar

The experimental flow chart is shown in Figure 1.

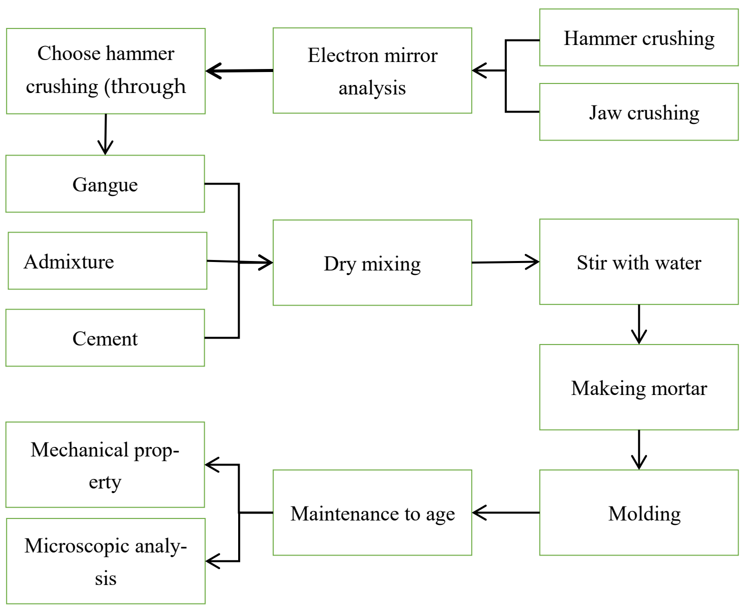



**Figure 1.** Experimental flow chart.

2.3.2. Dry-Mixed Mortar Preparation Process

(1) The gangue is broken in a hammer or jaw crusher and passed through a sieve to obtain the gangue of the required particle size. SEM analysis is performed on two kinds of crushed gangue, and the analysis results determined which crushing method to be used. The SEM analysis revealed that the hammer-crushing method is more suitable for crushing. Then, after weighing a certain amount of gangue, additive, and cement, they are poured into the containers and mixed thoroughly with the tool.

(2) Take a certain amount of water, add it to the container, and then use a stirrer to stir it evenly, followed by measuring its consistency. Using a consistency meter, follow the steps in JGJ/T 70-2009 for the test. Record data. Measure its water retention rate. Using the instruments required in the water retention experiment, the test was carried out according to the steps in JGJ/T 70-2009. Record the data and calculate the results.

(3) Then pour the mortar into the mold, make it molded, and then place it in a ventilated place to ensure that its temperature is approximately 25 °C, let it stand for 24 h, and after molding, release it from the mold. Use an air pump to align the small hole in the mold, and use the power of the air to blow it out. After the test mold is taken out, it is put into the maintenance box for maintenance until the expiration age. After the expiration age, the mold is taken out, the 7 d compressive strength is measured by the instrument, and the data is recorded.

### *2.4. Experimental Formula Design*

This experiment adopts the principle of a single variable. First of all, the performance effect of cement dosage on dry mix mortar is examined. Then, the performance effect of the admixture type on dry mix mortar is examined, and the minimum value of cement mixing is analyzed according to the performance impact, that is, the maximum value of gangue mixing and the type of admixture is determined. Specific configurations are shown in Table 4.

**Table 4.** The incorporation amount of gangue as well as the base ratio of different types of admixture.

| Coal Gangue (%) | Cement (%) | Admixture 1# (g/kg) | Admixture 2# (g/kg) | Water (mL/kg) |
|---|---|---|---|---|
| 92 | 8 | 0.045 | - | 185 |
| 90 | 10 | 0.045 | - | 185 |
| 88 | 12 | 0.045 | - | 185 |
| 85 | 15 | 0.045 | - | 185 |
| 83 | 17 | 0.045 | - | 185 |
| 80 | 20 | 0.045 | - | 185 |
| 75 | 25 | 0.045 | - | 185 |
| 92 | 8 | - | 0.045 | 185 |
| 90 | 10 | - | 0.045 | 185 |
| 88 | 12 | - | 0.045 | 185 |
| 85 | 15 | - | 0.045 | 185 |
| 83 | 17 | - | 0.045 | 185 |
| 80 | 20 | - | 0.045 | 185 |
| 75 | 25 | - | 0.045 | 185 |

The basic ratio of this experiment determines the cement dosage of 17% and the use of admixture 1# (Jiuzhu admixture) based on the original experiment. On this basis, the performance effect of the admixture dosage on the dry mix mortar is further examined, and the optimal dosage of the admixture 1# is determined according to the performance impact analysis of the dry mix mortar. The specific matching experiment is shown in Table 5.

**Table 5.** Data of base ratio of the spiking amount of admixture.

| Coal Gangue (%) | Cement (%) | Admixture 1# (g/kg) | Water (mL/kg) |
|---|---|---|---|
| 83 | 17 | 0 | 185 |
| 83 | 17 | 0.045 | 185 |
| 83 | 17 | 0.1 | 185 |
| 83 | 17 | 0.2 | 185 |
| 83 | 17 | 0.3 | 185 |
| 83 | 17 | 0.4 | 185 |
| 83 | 17 | 0.45 | 185 |

This experiment is based on the above two experiments, and the impact of water addition is further examined. In the above two experiments, the cement dosage was determined to be 17%, and the amount of admixture 1# was 0.2 g/kg. Based on these results, the performance effect of water addition on dry mix mortar was further examined, and the optimal use range of water addition was determined according to the performance impact analysis of dry mix mortar. The specific matching experiment is shown in Table 6.

**Table 6.** Data of base ratio of different water addition.

| Coal Gangue (%) | Cement (%) | Admixture 1#(g/kg) | Water (mL/kg) |
|---|---|---|---|
| 83 | 17 | 0.2 | 185 |
| 83 | 17 | 0.2 | 188 |
| 83 | 17 | 0.2 | 191 |
| 83 | 17 | 0.2 | 194 |
| 83 | 17 | 0.2 | 197 |
| 83 | 17 | 0.2 | 200 |

### *2.5. Performance Test*

#### 2.5.1. Grain Tickle Grading Experiment

Particle gradation experiments are performed according to the steps in JGJ 52-2006.

The specific operation is as follows:

(1) Weigh 500 g of the dried sample and place it on the uppermost screen (a square screen with a nominal diameter of 5.00 mm) of a set of screens arranged in order of screen size (large holes on top and small holes on bottom). Put the set of screens into the shaking screen machine and tighten them, and screen for 10 min; then take out the sets of screens, and then carry out hand screening on a clean shallow plate one by one according to the order of the screen holes from large to small, until the sieved amount per minute does not exceed 0.1% of the total sample. The passing particles are merged into the next screen, and hand sieved together with the sample in the next sieve. Proceed in this order until all the sieves are completed.

(2) Weigh out the spare amount of each sieve, accurate to 1 g. The sieve allowance of the sample in each size shall not exceed the quantity calculated according to Equation (1). Otherwise, the residual sample of the screen should be divided into two or several parts, again screening, and the sum of its screening allowance is the screening allowance of the screen.

$$G = \frac{A \times d^{1/2}}{200} \tag{1}$$

In the formula:

$G$—the sieve allowance g on a sieve
$A$—screen surface area( mm$^{2)}$
$d$—screen side length (mm)

(3) Weigh the mass of the remaining sample from each screen (accurate to 1 g), and the difference between the sum of the remaining amount of each screen and the remaining

amount in the chassis shall not exceed 1% compared with the total amount of the sample before screening.

(a) Calculate the score of the screen balance (the ratio of the screen balance of each screen to the total number of samples), and the calculation result is accurate to 0.1%.

(b) Calculate the cumulative sieve surplus (the sieve residual percentage plus the sum of the sieve above the sieve residual percentage), accurate to 0.1%.

(c) According to the average value of the cumulative sieve residue of two experiments, evaluate the particle distribution of the sample, accurate to 1%.

(d) The fineness modulus of sand is calculated according to Equation (2) and is accurate to 0.01.

$$M_X = \frac{(A_2 + A_3 + A_4 + A_5 + A_6) - 5A_1}{100 - A_1} \tag{2}$$

In the formula:

$M_X$—cumulative sieve residual rate/%. $A_1$, $A_2$, $A_3$, $A_4$, $A_5$, $A_6$—the cumulative percentage of the sieve of 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm, respectively.

(e) Take the arithmetic mean value of the results of the two experiments as the measurement value, accurate to 0.1. When the difference between the fineness modulus of the two experiments is greater than 0.20, a new sample should be taken for the experiment.

2.5.2. Consistency Experiments

Consistency is tested according to JGJ/T 70-2009. Pour the mortar into the container, tap it several times with the tool and tap it five to six times, then flatten the mortar surface. The upper pole is flush with the mortar surface, then the screw is twisted, and after 10 s, the value above the scale is read, that is, the consistency value.

2.5.3. Water Retention Rate Experiment

The water retention rate was tested according to JGJ/T 70-2009. Load the mortar mixture into the test mold, use the tool to insert and pound several times, scrape off the excess mortar, and then smooth its surface. Use a 45 μm standard sieve as a metal strainer and cover the mortar surface. Place the filter paper on the metal filter, and press the 2 kg heavy object onto the filter paper. Measure the quality of the filter paper after two minutes of standing. Mortar water retention rate is calculated as shown in Formula 3.

$$W = \left[1 - \frac{m_4 - m_2}{\alpha \times (m_3 - m_1)}\right] \times 100 \tag{3}$$

In the formula:

$W$—mortar water retention ratio (%)
$m_1$—drying mold mass (g)
$m_2$—filter paper before absorbing water mass (g)
$m_3$—mortar and try out total mass (g)
$m_4$—filter paper after absorbing water mass(g)
$\alpha$—mortar moisture content (%)

Pressure resistance is tested according to JGJ/T 70-2009. The mixed mortar is poured into a triple mold of 70.7 mm × 70.7 mm × 70.7 mm, and it is placed in the maintenance box after being pounded, vibrated, and smoothed, and the conditions in the maintenance box meet the temperature at 20 ± 5 °C. After 24 h of maintenance, the mold is released and put into the maintenance box for maintenance until the specified age, the damage load is determined, and the data is recorded. Formula 4 for calculating the compressive strength of the mortar cube is as follows:

$$f_{m,cu} = K\frac{N_u}{A} \tag{4}$$

In the formula:

$f_{m,cu}$—compressive strength (MPa)
$N_u$—destructive load (N)
$A$—pressure area ($mm^2$)
$K$—conversion coefficient, 1.35

## 3. Results Analysis and Discussion

### *3.1. Characterization of Gangue Samples*

#### 3.1.1. XRD Analysis of Gangue

Gangue is a kind of black rock with low carbon content and relatively hard content associated with coal seams during the coal formation process. It is a mixture of carbonaceous shale, carbonaceous sandstone, sandstone, shale, clay, and other rocks.

As shown in Figure 2, the main minerals in Guoshi gangue are quartz, kaolinite, pyrite, and calcite. Kaolinite in gangue corresponds to the diffraction peak of the (001) surface (2θ = 12.35°), and the diffraction peak corresponds to the (002) surface (2θ = 24.80°), Al and Si in kaolinite are important components in the activity of gangue, and the amount of kaolin stone phase will have a significant impact on the activity of gangue calcination.

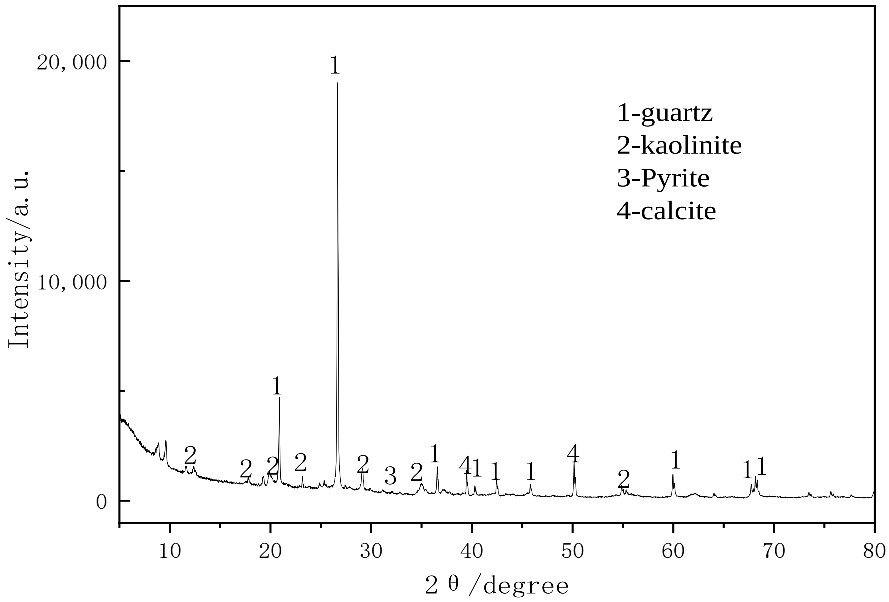



**Figure 2.** XRD patterns of raw coal gangue and roasted coal gangue.

#### 3.1.2. SEM Analysis of Gangue

Scanning electron microscopy analysis of samples with different crushing methods is shown in Figure 3. It can be seen from the Figure 3 that the gangue crushed by the jaw type is flaky, and the gangue crushed by the hammer is spherical particles, and the way the two are broken is not the same, resulting in the inconsistent shape of the coal gangue. In addition, the granular gangue can increase its compressive strength when preparing dry mix mortar, so the hammer crushing is preferred in the selection of coal gangue crushing method.

### *3.2. Performance Effect of Particle Size-Level Paired Dry-Mixed Mortar*

From Table 7, it can be seen that Gangue-1, Gangue-2, and Gangue-3 are used as the benchmark gangue for the preparation of dry-mixed masonry mortar, and the fineness modulus is in the range of 2.7 to 3.0, which belongs to medium sand. From Figure 4, it can be seen that the cumulative sieve residual rate of various particle sizes of the above gangue falls within the scope of the national standard grading zone II. zone, and the medium sand mentioned in JGJ 52-2006 is the most conducive to the preparation of dry-mixed mortar. It can be proved that the particle size gradation of coal gangue selected for this experiment meets the standard of medium sand in the national standard.

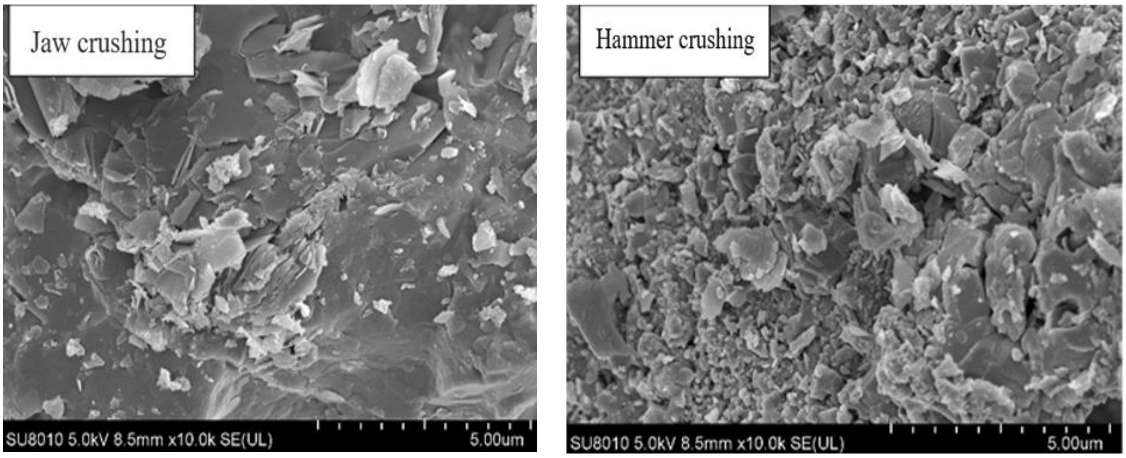



**Figure 3.** SEM of coal gangue under two crushing modes.

**Table 7.** The screen residue rate of benchmark sand.

| Cumulative Residue Ratio (%) mm / No. | 0.15 | 0.3 | 0.6 | 1.18 | 2.36 | 4.75 | Granularity Series | Configure Mortar Intensity Level |
|---|---|---|---|---|---|---|---|---|
| Gangue-1 | 95.67 | 87.79 | 68.22 | 40.54 | 3.01 | 1.60 | 2.95 | M7.5 |
| Gangue-2 | 95.12 | 87.31 | 68.33 | 41.55 | 3.98 | 1.50 | 2.96 | M7.5 |
| Gangue-3 | 92.58 | 83.49 | 64.33 | 38.33 | 3.29 | 1.57 | 2.86 | M7.5 |
| National Standard Zone 2 Requirements Scope | 90~100 | 70~92 | 41~70 | 10~50 | 0~25 | 0~10 | medium sand 3.0~2.3 | / |

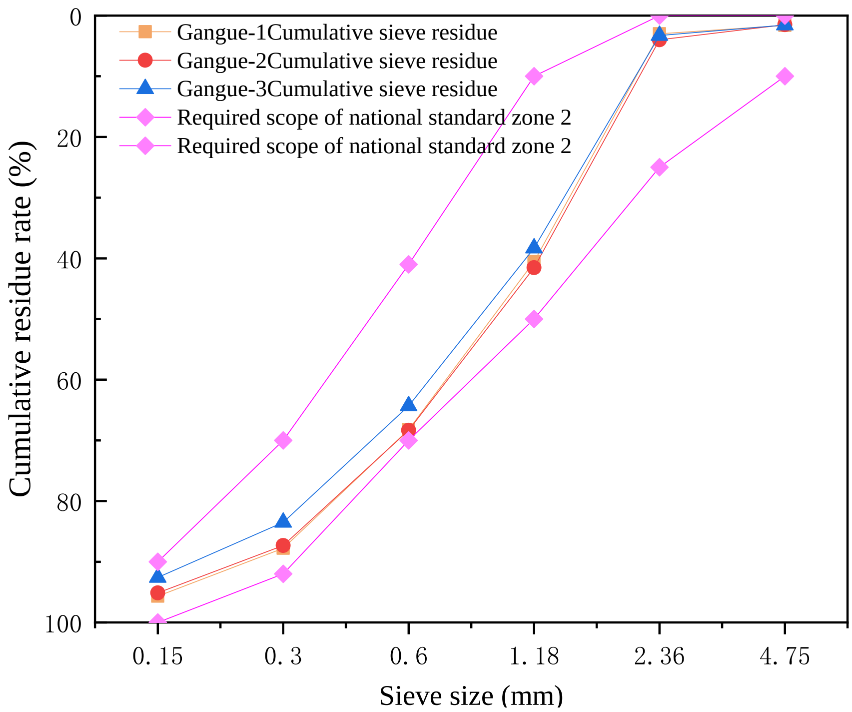



**Figure 4.** Particle grading curve of dry-mixed mortar.

When configuring dry-mixed mortar, select medium sand first. If coarse sand is selected, it is necessary to increase the sand rate and maintain sufficient cement quantity to meet the requirements of dry-mixed mortar. When selecting fine sand, it is necessary to consider reducing the sand rate to meet the corresponding requirements. Based on the above analysis, the final choice for this paper is medium sand.

### 3.3. Analysis of the Effect of Cement Mixing on the Performance of Dry-Mix Mortar

According to GB-T 25181-2019, ready-mixed mortar in ordinary masonry mortar requires factory testing projects to include compressive strength, consistency, and water retention rate of the three indicators, so this experiment needs to meet the three indicators to achieve the highest economic benefits on the premise of the specified requirements.

The compressive strength of mortar refers to the extreme failure load stress that mortar can withstand per unit area. Compressive strength is an important indicator for evaluating industrial production, building safety, and construction applications.

The consistency of the mortar can indicate the fluidity of mortar. The greater the consistency, the better the fluidity and the better the fluidity of the mortar, which is conducive to the smoothing of the mortar. At the time of construction, fluidity is an important performance indicator. With the passage of time, the mineral components $C_3A$ and $C_3S$ in the cement particles hydrate with water to form calcium alum and C-S-H gels, so a large amount of free water is consumed, which reduces the fluidity of the dry-mixed mortar, resulting in a smaller consistency of the dry-mixed mortar. At the same time, the cement hydration product will increase, resulting in cement particles gathering, so that the fluidity of the dry-mixed mortar will decrease, so the consistency of the mortar will also be reduced.

The water retention of mortar is an important performance index to evaluate the ability of the newly mixed mortar to retain moisture, the construction performance of the newly mixed mortar, and the internal structural stability during the transportation and storage of the newly mixed mortar, which has an important impact on the performance of the mortar after hardening. If the water retention of the mortar is poor, it will lead to poor construction of the mortar. When it is serious, the cementation material in the mortar will not be fully hydrated, resulting in low strength, especially the interfacial strength between the mortar hardener and the base layer, resulting in problems such as cracking and shedding of the mortar.

As can be seen from Figure 5, as the amount of cement is increased, the compressive strength increases. When using the 1# admixture with the percentage of cement dosage at 8%, 10%, 12%, 15%, 17%, 20%, and 25%, the 7 d compressive strength of the mortar is 2.7 MPa, 4.3 MPa, 6.2 MPa, 12.1 MPa, 9.4 MPa, 21.9 MPa, and 24.3 MPa, respectively. When using the 2# admixture with the percentage of cement dosage at 8%, 10%, 12%, 15%, 17%, 20%, and 25%, the 7 d compressive strength of the mortar is 2.7 MPa, 4.0 MPa, 6.1 MPa, 10.1 MPa, 9.2 MPa, 16 MPa, and 23.7 MPa, respectively. From these two sets of data, it can be seen that as the amount of cement is gradually increased, the compressive strength is also gradually increasing. As can be seen from the histogram, each value of admixture 1# is slightly higher than admixture 2#. Thus, in terms of the numerical value of the compressive strength of the mortar, admixture 1# has a better effect than the 2# admixture.

As can be seen from Figure 5, as the amount of cement is increased, the change in consistency and water retention is small. However, it can still be seen that the consistency is increasing, and the water retention rate is maintained in a stable state. Although the effect of the admixture on the water retention rate is comparable, it can be seen from the figure that the effect of admixture 1# on consistency is better than that of the admixture 2#.

In summary, in these two admixtures, for the effect of compressive strength of 7 d and the influence of mortar consistency, admixture 1# is preferred.

In the selection of the best amount of cement, priority is given to the change of compressive strength, because of the need to make M7.5 level of dry mix mortar. It can be seen from the figure that the cement mixing amount is 15% when the conditions are met. When the dry mix mortar is used as masonry mortar, its strength is best when not exceeding 20 MPa. Thus, the cement dosage of the mortar should be below 20%, and the two comprehensive considerations of the cement dosage are 17%. The mortar consistency and water retention rate at this time meet the conditions.

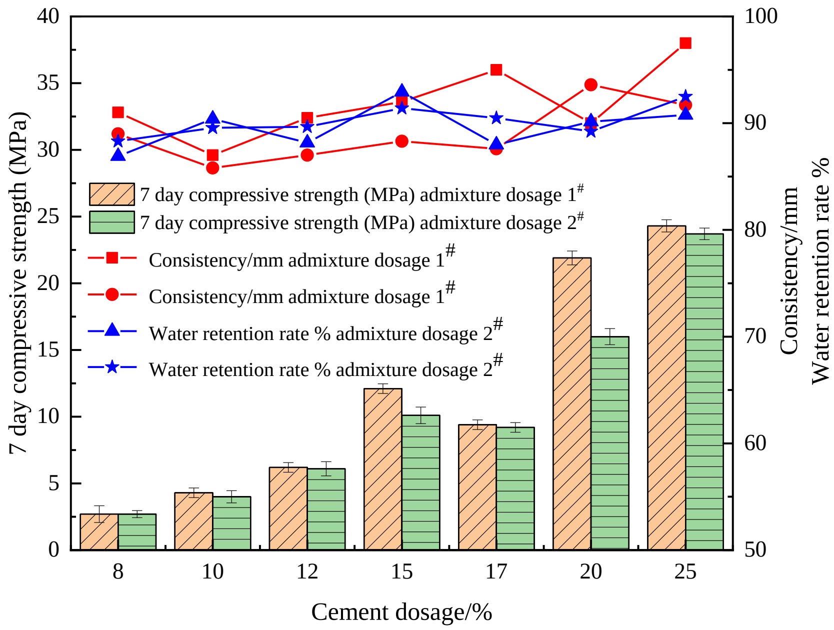



**Figure 5.** Influence of cement content on dry-mixed mortar.

### *3.4. Analysis of the Effect of Admixture Dosage on the Performance of Dry-Mixed Mortar*

The effect of admixture content on the properties of dry-mixed mortar is shown in Figure 6. First of all, the histogram is analyzed. It can be seen that with the increase in the dosage of the admixture, the compressive strength of 7d is relatively stable between 0.2 and 0.4 g/kg, and the value at this time is large. Secondly, it can be seen from the figure that the consistency and water retention rate of mortar in the range of 0.2~0.4 g/kg are also relatively stable. The more economical amount of additives is selected from an economic point of view, the less the amount of admixture is selected, and accordingly, the better the values of both meet the standards of dry-mixed mortar as ordinary masonry mortar.

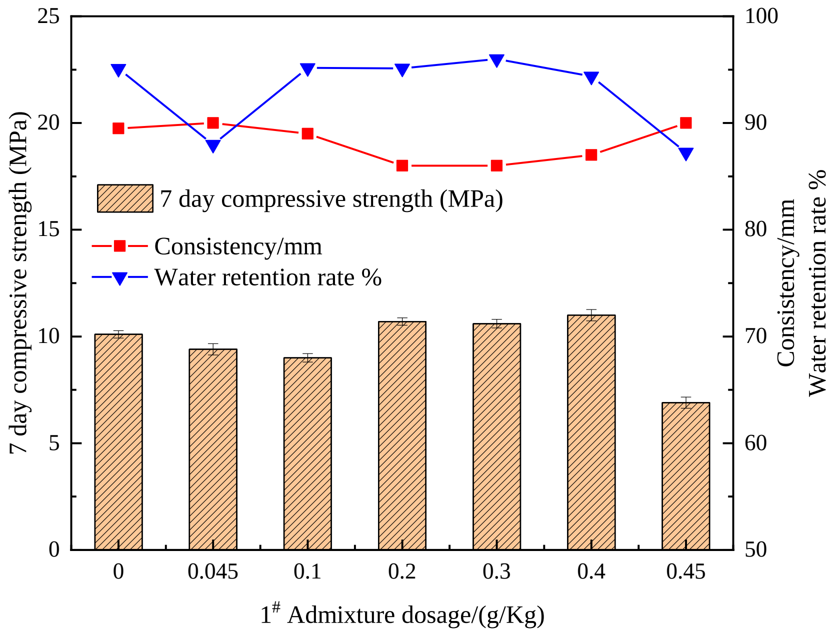



**Figure 6.** Effect of admixture content on properties of dry-mixed mortar.

Based on the above considerations, i.e., the performance effect of dry-mix mortar, the admixture dosage of 0.2 g/kg is finally selected as the optimal dosage of the admixture.

### *3.5. Analysis of the Effect of Water Addition on the Performance of Dry-Mixed Mortar*

As can be seen from Figure 7, the consistency becomes larger and larger as the amount of water used increases. When the water addition is 185 mL, 188 mL, 191 mL, 194 mL, 197 mL, and 200 mL, the consistency of the mortar is 89 mm, 89 mm, 89.5 mm, 90 mm, 91.5 mm, and 91.5 mm, and the water retention rate of the mortar is 95.12%, 93.88%, 93.74%, 93.15%, 92.11%, and 92.37%, respectively. At this time, the consistency of the mortar is increasing, and the water retention rate of the mortar is decreasing. Since the overall value of the water retention rate is large and meets the standard, the consistency standard according to the masonry mortar (GB-T 25181-2019) is above 90 mm, so it can be concluded that when the water is added to 194~200 mL/kg, the consistency meets the standard, and the water retention rate at this time also meets the standard.

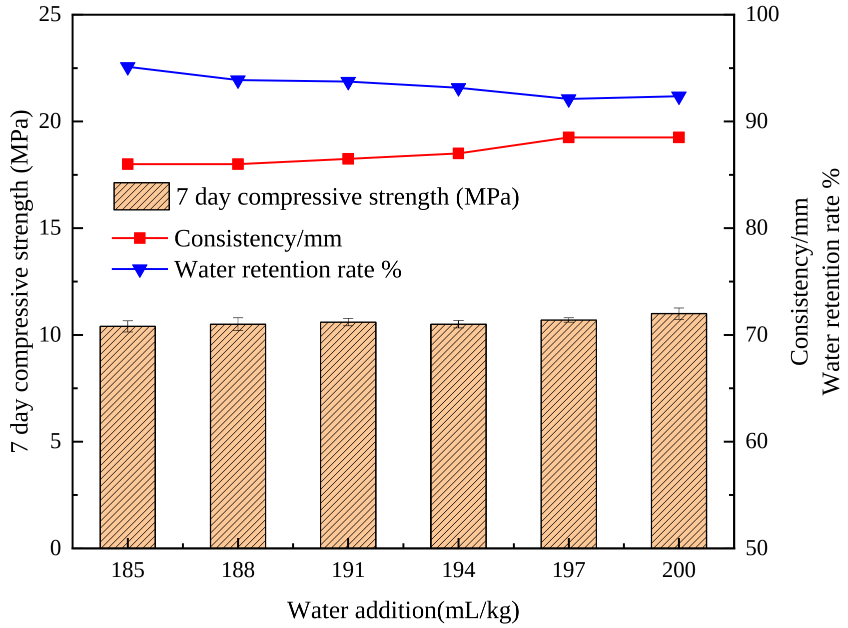



**Figure 7.** Effect of water addition on properties of dry-mixed mortar.

And from the analysis of compressive strength, the amount of water added to the dry-mixed mortar compressive strength is not obvious, so according to the above conclusion, the water addition of 194~200 mL/kg is the best water addition range.

### *3.6. Characterization of Dry-Mixed Mortar Samples*

#### 3.6.1. XRD Analysis of Dry-Mixed Mortar

As shown in Figure 8, the dry-mixed mortar prepared is a mortar made of coal gangue, cement, admixture, and water mixed in a certain proportion.

It is mainly composed of tricalcium silicate ($3CaO{\cdot}SiO_2$, abbreviated as $C_3S$), a content of 37% to 60%; dicalcium silicate ($2CaO{\cdot}SiO_2$, abbreviated as $C_2S$), a content of 15% to 37%; tricalcium aluminate ($3CaO{\cdot}\ Al_2O_3$, abbreviated as $C_3A$), a content of 7% to 15%, and iron aluminum tetracalcium ($4CaO{\cdot}Al_2O_3{\cdot}Fe_2O_3$, abbreviated as $C_4AF$), composed of 10% to 18%. Due to the hydration of $C_3S$ and $C_3A$ in dry-mixed mortar forming calcium alum, free water is consumed and the consistency of dry-mixed mortar is affected.

#### 3.6.2. SEM Analysis of Dry-Mixed Mortar

Figure 9a shows a 10,000-fold magnification of the dry-mixed mortar sample, and Figure 9b displays a 500-fold magnification of the dry-mixed mortar sample. As shown in Figure 9a, the dry-mixed mortar sample does not have excessive porosity, indicating that the dry-mixed mortar sample performs well. From Figure 9b, it can be seen that the structure of this sample is very dense, with more strip fibers, which can enhance the strength of dry-mixed mortar. The dry-mixed mortar obtained by this experiment has a small pore, where the calcium aluminate presence is small. Thus, the crystal will produce anisotropy, and the needle-like structure can improve the stability of the dry-mixed mortar.

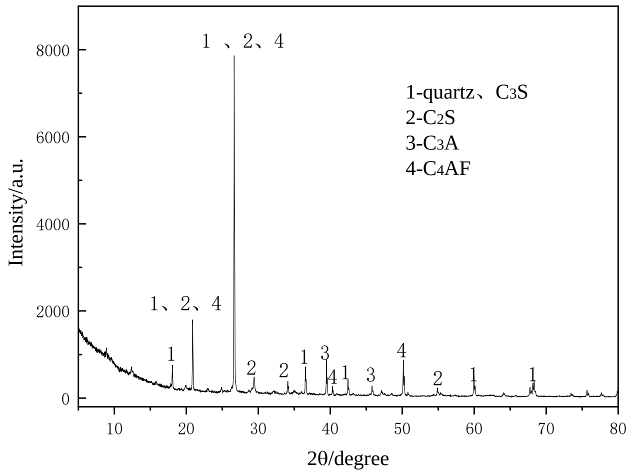
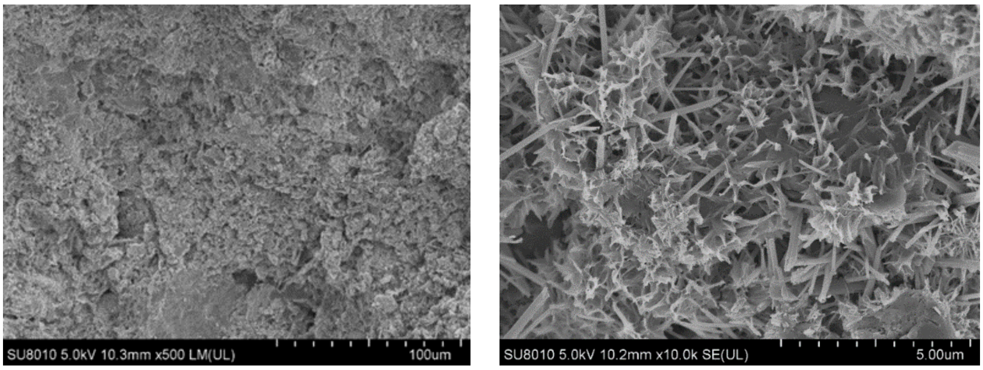



**Figure 8.** XRD of dry-mixed mortar cured for 7 days after molding.




(**a**) (**b**)

**Figure 9.** SEM photos of dry-mixed mortar after curing for 7 days. (**a**) ×500 and (**b**) ×10k.

Dry-mixed mortar is a mixture of cement, gangue, and admixture (active agent), which is mixed and produced by professional manufacturers after measurement and mixed with water at the construction site in accordance with the prescribed proportion. Compared with freshly mixed mortar, dry-mixed mortar has many advantages, such as environmental protection, stable quality, strong applicability, the reduced labor intensity of construction personnel, and the development of bulk cement; therefore, it has been widely used in engineering practice [17,18].

The work presents a wide range of raw materials with superior product quality and low cost. It reveals that full use of gangue has a huge negative impact on the environment to produce dry-mixed mortar with market prospects. It not only reduces the cost of raw materials and environmental pollution but also reduces energy consumption, in line with the national energy conservation and emission reduction policy [19,20]. At the same time, the product meets the requirements of ordinary plaster mortar and masonry mortar in the ready-mixed mortar standard GB/T25181-2019. At the same time, the product meets the requirements of ordinary plaster mortar and masonry mortar in the ready-mixed mortar standard GB/T25181-2019. To solve the problem of low added value such as coal gangue polluting the environment, occupying land, and being limited to brick making, the use of high-tech content and high added value of coal gangue can not only produce good economic benefits, environmental benefits, and ecological benefits but also have a strong market competitive advantage and promotion and application prospects [21].

### *3.7. Analysis of the Strengthening Mechanism of Additives*

XRD spectrum of 1# and 2# admixtures are shown in Figure 10. It can be seen from the figure that the 1# additive is mainly composed of limestone ($CaCO_3$), and the 2# additive is mainly composed of limestone ($CaCO_3$) and quartz ($SiO_2$). In the production process of the cement industry, various mixtures are often added to improve performance, such as limestone, fly ash, slag, etc. [22]. The main component of limestone is calcium carbonate (CC), which not only has physical effects of filling and dilution but also has chemical effects [23]. Limestone can stabilize the structure, reduce shrinkage, and make the concrete more waterproof [24]. In the production process of sulphoaluminate cement, CC is often added to alleviate the strength reversion in the later period. This is because in addition to ettringite (AFt), calcium sulphoaluminate (AFm), and aluminum glue ($AH_3$) in the hydration products, CC will also react to generate calcium carboaluminate hydrate that is conducive to strength improvement in the later stage [25]. Hargis et al. [26] studied the hydration products of calcium sulphoaluminate ($C_4A_3S$) in the presence of CC, and found that CC and $C_4A_3S$ would form single-carbon calcium carboaluminate hydrate (Mc). Calcium carbonate also has hydration activity with tricalcium aluminate ($C_3A$), calcium aluminate (CA), and other aluminate minerals. The main products are Mc and three-carbon type hydrated calcium carboaluminate (Tc) [27].

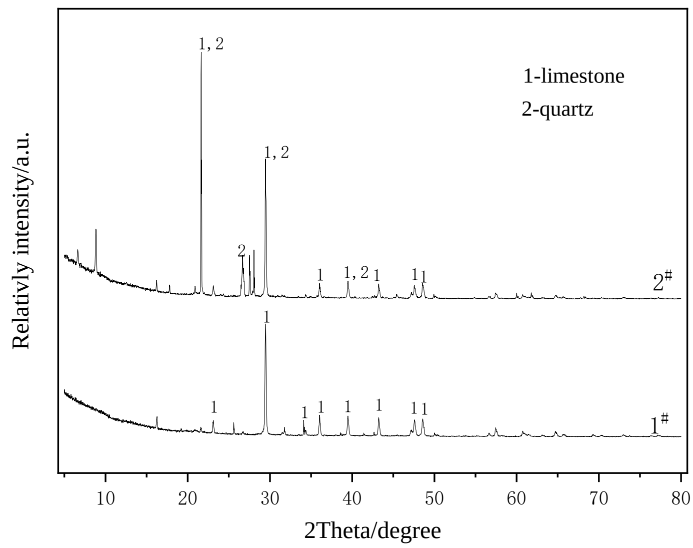



**Figure 10.** XRD spectrum of 1# and 2# admixtures.

Song et al. [28] reported that the degree of hydration reaction of low calcium cement (LCC) for one day was relatively low, and the amount of CC had little influence on the early mechanical properties of LCC. Adding an appropriate amount of CC mainly improved the mechanical properties of LCC in the later stage. When the content of CC is 5%, the 28-day strength growth rate of low calcium cement can reach 10.7%. The hydration activity of CC is limited, and further increasing the content of CC (10~20%) will lead to a continuous decline in the mechanical properties of LCC in the later stage. The addition of CC changed the hydration process of LCC, which not only slowed down the initial hydration reaction rate but also effectively reduced the hydration heat release within 180 h. Most of the CC plays the role of aggregate filling, and only a small part of the CC can undergo active reaction to generate Hc in the later stage of hydration. At the same time, CC can also promote the formation of hydrated calcium aluminum melilite ($C_2ASH_8$) in the slurry. The lamellar calcium aluminate hydrate (Hc) and hydrated calcium aluminum melilite ($C_2ASH_8$) jointly improve the slurry structure and reduce the pore content.

2# admixture contains calcium carbonate and a small amount of silicon dioxide, and its reinforcement effect is not as good as 1# admixture. The reasons need to be further studied.

## 4. Conclusions and Outlook

(1) The sample crushed by hammer crushing is more in line with the particle shape requirements for the preparation of dry-mixd mortar than the jaw type crushing method, and its compressive strength can be enhanced when preparing dry-mixed mortar.

(2) When studying the water retention of dry-mixed mortar, it is shown that when the admixture is 1# admixture, the water-ash ratio is more than 18.4%, the maximum amount of gangue is 83%, and the water retention effect is best.

(3) For the consistency experiment of dry mix mortar, the biggest impact on it is the water-to-ash ratio and the difference with the water retention are that the larger the water-ash ratio, the greater the consistency, and the worse the water retention. Thus, it is necessary to find the best dosage between the two to ensure that the consistency is up to standard and that the water retention effect is sufficient. Therefore, a water-ash ratio of 19.2% is selected.

(4) The greatest impact on the strength of dry-mixed mortar is the amount of gangue mixed. From the above results, the best gangue dosage is 83%. The strength of the dry-mixed mortar at this time can meet the strength specified in GB/T 25181-2019 in the national standard, and the amount of cement can be reduced to a certain extent.

(5) The optimal dosage of gangue is 83%, the amount of cement is 17%, the dosage of admixture 1# is 0.2 g/kg, and the water addition is 194~200 mL/kg. The consistency at this time reaches 91.5 mm, the water retention rate reaches 92.11%, and the compressive strength of 7 d can reach 10.6 MPa. It basically meets the requirements of dry-mixed mortar for ordinary plastering and masonry mortar (GB-T 25181-2019).

In this study, coal gangue, which has a huge negative impact on the environment, was used to produce dry-mixed mortar with market prospects. It not only reduces the cost of raw materials and lessens environmental pollution but also decreases energy consumption, which is in line with the national energy conservation and emission reduction policy. At the same time, the product meets the requirements of dry-mixed mortar and has strong market competitive advantages and application prospects.

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