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Preparation and Properties of Masonry Mortar from Spontaneous Combustion Coal Gangue

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To solve the problem of gangue stockpiling, this paper intends to study the feasibility of preparing masonry mortar based on spontaneous combustion gangue. After crushing the spontaneous combustion gangue, the gangue below 4.75 mm was selected, and substituted manufactured sand to prepare masonry mortar in equal quantity. The single factor test method was used to select the replacement rate of spontaneous combustion gangue, water-binder ratio (W/B) and water reducer dosage as variables to explore their effects on the basic properties of fresh mortar mixtures, such as fluidity, apparent density and water retention of fresh mortar, and the mechanical properties of hardened mortar. The anti-frost resistance of gangue mortar was evaluated by a freezing-thawing cycle test. SPSS.20 software was used for variance analysis, and the results showed that the replacement rate of spontaneous combustion gangue, W/B and water reducer dosage on mechanical properties of mortar differences are significant ($P < 0.001$). With the increase of the replacement rate of spontaneous combustion gangue, the mortar strength decreases, and with the rise of W/B, the mortar strength raises first and then reduces, while with the increase of the water reducer dosage, the mortar strength increases first and then decreases. Spontaneous combustion gangue mortar shows better anti-frost resistance under the freezing-thawing cycle. After 50 freezing-thawing cycles, the maximum mass and strength loss rate of mortar specimens are 2.4 % and 12.67 %, respectively. When the replacement rate of spontaneous combustion coal gangue is 100 %, the mechanical properties and anti-frost resistance of mortar both meet the requirements of the standard and realize the maximum utilization of gangue waste resources. This paper aims to provide theoretical support for the application of spontaneous combustion gangue in masonry mortar.

Keywords: spontaneous combustion coal gangue mortar, single factor test, variance analysis, mechanical property, durability property.

1. INTRODUCTION

Coal gangue is the solid waste generated during the coal mining and washing processes. According to the source and natural existence state, it can be divided into two categories: one is the gangue without calorific value, formed after spontaneous combustion, which is red in appearance and rich in iron, and is known as spontaneous combustion gangue; The other is the gangue that is decomposed by the wind and rain under the natural conditions. The crystal type of the gangue structure is relatively stable, and its atoms, ions, molecules and other plasma points are arranged according to certain rules, and basically have no activity, which is called fresh gangue (weathered gangue) [1, 2]. In China, the output of gangue is approximately 15 % – 20 % of the output of raw coal. Every year, a large amount of gangue is produced during the coal mining process. According to statistics, China has accumulated more than 5×10^9 t of gangue, which is increasing at a rate of $(2.7-3.5)\times10^8$ t per year [3 – 5]. These large gangue storage areas not only occupy land resources, but also destroy the soil environment and geological conditions, resulting in the deterioration of the atmosphere and water environment [6 – 8].

A large amount of gangue storage is a common problem in coal mines of various countries. How to recycle the gangue after mining has become a hot topic concerned by researchers in various countries. At present, the application of gangue in the field of building materials mainly focuses on the production of cement, light aggregate, and concrete with gangue. Zhang et al. [9] discussed the volcanic ash activity, cement hydration, mechanical properties and durability of activated gangue mixed with cement-based materials, providing theoretical guidance for the resource utilization of gangue in cement-based building materials. Zhu et al. [10] studied the influence of high temperature calcination process on the chemical composition, microstructure and applicability of gangue as aggregate in concrete production, which showed that the crushing value of gangue increases after calcination, the prepared concrete interface is porous, and the water absorption rate is significantly improved. In addition, Li et al. [11] reviewed the research status and progress of producing brick products and hollow blocks with gangue as the main raw material. Hu et al. [12] prepared hollow block with gangue as raw material, analysed the physical properties of gangue, and found that compared with traditional hollow blocks with smaller density and higher porosity.

The comprehensive utilization rate of gangue in China is low, only reaching about 60 % [13], and a complete system has not yet been formed in the preparation of building materials from gangue. At present, there are few studies on gangue mortar, especially about the mechanical properties and durability of gangue in masonry mortar. This paper takes spontaneous combustion gangue as raw material to prepare masonry mortar, and studies the basic

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properties, mechanical properties, and durability of gangue mortar, in order to maximize the utilization of coal gangue waste resources and provide theoretical guidance and technical support for the commercial application of gangue mortar.

2. EXPERIMENTAL METHODS

2.1. Materials

Fine aggregate: spontaneous combustion coal gangue from Fengfeng Mining Area of Handan City, Hebei Province, China, which is red-brown, dense, hard and wear-resistant, is crushed and screened to obtain fine aggregate gangue with a particle size of 0 – 4.75 mm. The manufactured sand was produced by Road and Bridge Manufactured Sand Co., Ltd. in Wu'an city, Hebei Province, China. Grading curves of gangue fine aggregate and manufactured sand are presented in Fig. 1, and their physical properties are shown in Table 1. The results show that the grading curves of gangue fine aggregate and manufactured sand are similar, which both are in the second area.

Cement: with 28 d flexural strength of 8.8 MPa and 28d compressive strength of 51.2 MPa, P O 42.5 ordinary Portland cement is produced by Hebei Cheng'an Jinyu Taihang Co., Ltd.

Water reducing agent: with solid content of 40 % and water reduction rate of 20 %, polycarboxylate super-plasticizer is purchased from Shanghai Chenqi Chemical Technology Co., Ltd.

Water: tap water.

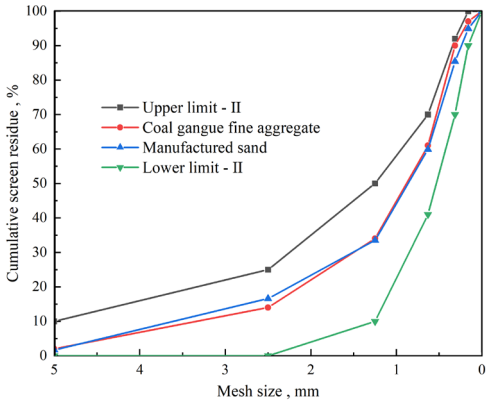


Fig. 1. Grading curves of coal gangue fine aggregate and manufactured sand

2.2. Preparation

To maximize the utilization rate of gangue and study the feasibility of completely replacing fine aggregate, with M30 masonry mortar as the design target, the single factor test method was used to study the effects of the proportion of gangue and manufactured sand, water-binder ratio (W/B) and water reducer dosage on mechanical strength and anti-frost resistance of masonry mortar. When analyzing the influence of the proportion of gangue in the aggregate, the mass ratio of fixed cement, aggregate, water and water reducer is 1:2.64:0.65:0.01. The mass fraction of gangue in aggregate (manufactured sand and gangue) is 40 %, 60 %, 80 % and 100 %, respectively, and the samples are named as GS1, GS2, GS3 and GS4. To facilitate comparison, when analyzing the impact of W/B, adjust based on GS2 (coal gangue replacement rate 60 %), that is, the mass ratio of fixed cement, gangue, manufactured sand and water reducer is 1:1.05:1.58:0.01. The W/B is 0.63, 0.65 and 0.67, respectively, and the samples prepared are marked as SJ1, SJ2 and SJ3. When analyzing the effect of water reducer, adjust based on GS2 (coal gangue replacement rate 60 %) and SJ2 (W/B is 0.65), the mass ratio of fixed cement, gangue, manufactured sand, and water is 1:1.05:1.58:0.65. The water reducer dosage is 0.8 %, 1.0 % and 1.2 % of the cementitious material, respectively, and the samples obtained are recorded as WJ1, WJ2 and WJ3.

Considering the strong water absorption of gangue fine aggregate, mortar in the process of preparation will absorb a large amount of mixing water, and reduce mixture fluidity, based on a large number of tests, our group, coal gangue was pre-moistened with additional water, that is, water (total aggregate×mass fraction of coal gangue × water absorption rate ×80 %) was first added to moisten coal gangue, and then stood for 60 min to make it fully absorb water. Then, the wetted gangue, manufactured sand and cement are placed into the mortar mixing pot, and stirred with water for 3 min. Then the mixtures were immediately filled into the mold and placed on the shaking table to vibrate for 60 s. After the surface was smoothed, it was immediately covered with plastic wrap and maintained at a temperature (20 ± 5) ℃ and relative humidity > 50 % for 24 h before removing the mold. Finally, they are put into the standard maintenance room (temperature 20 ± 2 ℃, relative humidity ≥ 90 %), taken out after the specified age, dried the surface moisture, and tested for the relevant performance.

2.3. Test methods

Based on the Chinese norm JGJ 70-2009 for fresh mortar mixtures, the basic performance test such as fluidity, apparent density and water retention are tested. Based on the Chinese standard GB/T 17671-2020 and research requirements, the mortar mechanical properties are tested, with the size of 40 mm × 40 mm × l60 mm prism specimens. The mortar specimens are tested for flexural strength, and then the compressive strength test.

Table 1. Physical properties of spontaneous combustion coal gangue and manufactured sand

Materials	Moisture content, %	Water absorption, %	Silt content, %	Volume expansibility, %	Crushing index, %	Bulk density, g/cm^3	Apparent density, g/cm^3
Spontaneous combustion coal gangue	9.65	5.77	12.4	1	37.3	1.23	2.34
Manufactured sand	5.15	1.26	7.6	0	26.6	1.35	2.55

For the compressive strength test, the compaction area is 40 mm × 40 mm [8, 14].

Based on the Chinese norm JGJ 70-2009, the freezing resistance of mortar is tested. Six groups (three pieces in each group) of cube specimens with a size of 70.7 mm × 70.7 mm are prepared for each mixing ratio, which were used as 5, 25 and 50 times freezing-thawing test specimens and non-freezing-thawing test specimens, respectively [15].

3. RESULTS AND DISCUSSION

3.1. Basic performance of fresh mortar

3.1.1. Fluidity

Fig. 2 shows the fluidity test of each set of mortar specimens. With the increase of gangue replacement rate, the fluidity of mortar decreases gradually. This is due to gangue having strong water absorption, in the process of mortar mixing, gangue aggregate, which has not reached saturation after pre-wetting treatment, will continue to absorb water for mixing, resulting in reduced moisture and fluidity in the mixtures.

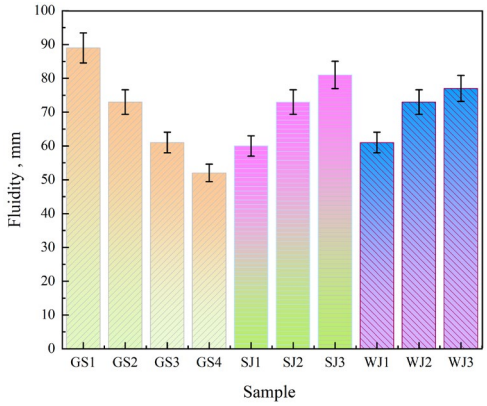


Fig. 2. Fluidity of fresh coal gangue mortar

The result of Chen et al. [16] showed that the increase in spontaneous combustion gangue replacement rate reduces the concrete liquidity, when the gangue replacement rate was 50 % and 100 %, the C30 concrete mixtures slump was reduced by 7.03 % and 10.81 % respectively. With the increase of W/B and water reducer dosage, the fluidity of mortar mixtures increases. The increase of the W/B directly increases the moisture in the mortar mixtures and improves the fluidity of the mortar [17]. Water reducer is a polycarboxylic based surfactant, with a hydrophilic end and hydrophobic end, which can disperse cement particles in mortar mixtures, destroy the flocculation structure formed by cement slurry, release the water wrapped by cement particles, and improve the fluidity of mixtures.

3.1.2. Mass density

Fresh mixing coal gangue mortar the mass density of the test result is shown in Fig. 3. As the proportion of gangue increases from 40 % of GS1 to 100 % of GS4, the mass density of fresh mortar decreases gradually. Since gangue aggregate has a large voiding ratio and high-water absorption, the apparent density of gangue is less than that of the manufactured sand. Moreover, the rough and irregular appearance of gangue aggregate hinders the compaction of mortar mixtures during the demoulding process to a certain extent.

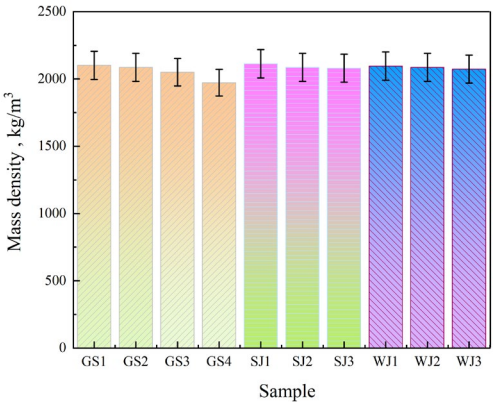


Fig. 3. Mass density of fresh coal gangue mortar

As a result, with the increase of gangue replacement rate, the mass density of the mixtures also decreases. With the increase of W/B (from 0.63 of SJ1 to 0.67 of SJ3), the mixing water increases when the cement amount is unchanged, and the cement paste becomes thinner, leading the mass density of the mortar to decrease. With the increase of the water reducer dosage (from 0.8 % of WJ1 to 1.2 % of WJ3), the mortar density showed a continuous decrease. The addition of water reducer can increase the fluidity, but also cause the formation of micropores in the mortar mixtures, resulting in a decrease in mass density. The minimum mass density of these fresh mortars is 1972 kg/m^3, but it still meets the requirements of dry-mix mortar density (≥ 1800 kg/m^3) in the Chinese norm JG/T230-2007.

3.1.3. Water retention

Fig. 4 shows the water retention test of mortar specimens in each group. The spontaneous combustion gangue mortars in every group have better water retention capacity, and the minimum water retention capacity of fresh mortar is 91.2 % (≥ 88 % in the Chinese National Standard JG/T230-2007), which meets the requirements of water retention capacity of dry-mix mortar.

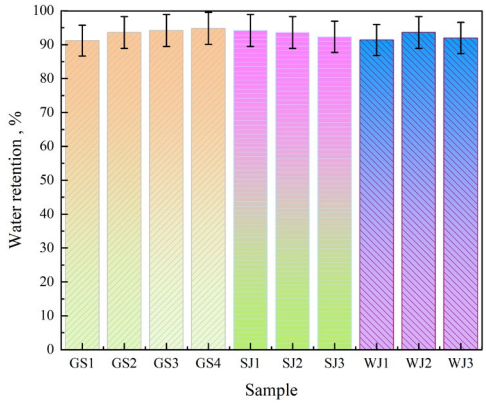


Fig. 4. Water retention of fresh coal gangue mortar

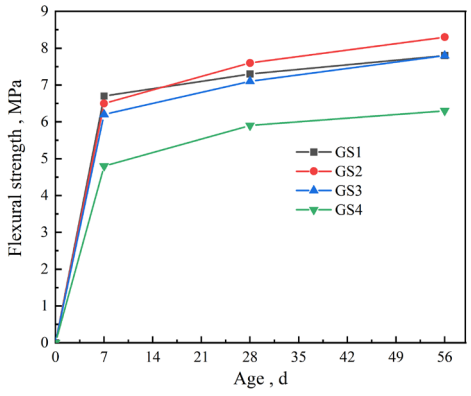
With the increase in gangue replacement, water retention is also raising. The particle size of aggregate is

the most factor influencing mortar water retention. The larger the particle size, the greater the mortar weepage attribute, and the worse the water retention [18]. Compared to manufactured sand, gangue aggregate particles of large particle size number is less, so the greater the gangue replacement rate, the better the fresh mortar mixtures water retention. With the rise of W/B, free water gradually increases, and the occurrence time of cement setting and hardening is prolonged, leading to the decrease in mortar water retention. The increase of water reducer dosage makes the water retention rise first and then decline, the appropriate dosage enables improvement the mortar water retention. However, the excessive dosage will cause fresh mortar weepage [19], and a large amount of free water will spill out of the mortar surface, affecting the condensation and hardening of cement and reducing the water retention performance. With the gangue replacement rate of 100 %, W/B of 0.63 and the water reducer dosage of 1%, the water retention of the three groups reaches the maximum, which is 94.8 %, 94.2 % and 93.6 %, respectively.

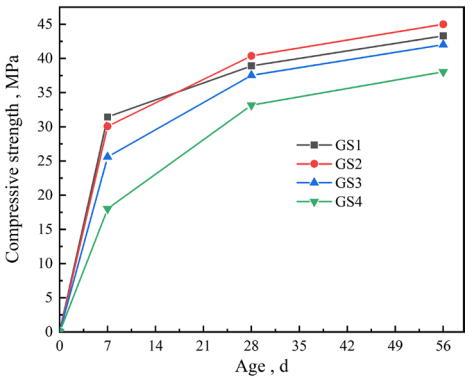
3.2. Mechanical strength of hardened mortar

3.2.1. Effect of replacement rate of spontaneous combustion coal gangue

The effect of gangue fine aggregate content on the mechanical strength of mortar is shown in Fig. 5.



a



b

Fig. 5. Effect of gangue fine aggregate content on the mechanical strength of mortar: a – flexural strength; b – compressive strength

At 7d of hardened mortar specimens, GS1, GS2, GS3 and GS4 group of flexural strength were 6.7, 6.5, 6.2 and 4.8 MPa, and their compressive strength were 31.4, 30.1, 25.6 and 18.0 MPa. The flexural and compressive strength decreases with increasing gangue replacement rate. According to the physical properties of spontaneous combustion coal gangue and manufactured sand in Table 1, the crushing index of mechanized sand is greater than that of gangue. When they cooperate as fine aggregate to provide support for mortar, the greater the replacement rate of gangue, the smaller the early mechanical strength of mortar. At 28d and 56d, the flexural strength and compressive strength at the same age increased first and then decreased with the increase of gangue replacement rate, and the mechanical strength of GS2 group was the best. At 28d, GS2 flexural strength was 7.6 MPa, increasing 4.1 %, 7 % and 28.8 % over GS1 (7.3 MPa), GS3 (7.1 MPa) and GS4 (5.9 MPa), respectively, and the G2 compressive strength was 40.4 MPa, which was 3.9 %, 7.7 % and 21.7 % higher than that of GS1 (38.9 MPa), GS3 (37.5 MPa) and GS4 (33.2 MPa), respectively. At 56d, GS2 flexural strength was 8.3 MPa, increasing 6.4 % and 31.7 % over GS1 (7.8 MPa), GS3 (7.8 MPa) and GS4 (6.3 MPa), respectively, and the compressive strength was 45 MPa, which was 3.9 %, 7.1 % and 18.4 % over GS1 (43.3 MPa), GS3 (42 MPa) and GS4 (38 MPa), respectively. This is determined by the two opposite effects of gangue aggregate on mortar: on the one hand, spontaneous combustion gangue has low pozzolanic activity, and will have a secondary hydration reaction with cement hydration products [8, 20], generating more gel products, improving the interface structure and performance between cement slurry and aggregate, and showing the improvement of mortar strength. On the other hand, gangue aggregate has strong water absorption [21]. Although the aggregate has been prewetted with additional water before the test, the unsaturated aggregate will continue to absorb water, which makes it difficult for cement to hydrate when gangue is highly substituted for mechanized sand, and the cement hydration is insufficient, resulting in a significant decrease in strength.

Using SPSS.20 software analysis of variance for the 28d mechanical strength of the four groups of mortar, the results are shown in Table 2. According to the results of variance analysis: the sum of squares of different gangue replacement rates is 105.441 inter-group and 1.909 intra-group, and the sum of square inter-group of the F is 248.530. The gangue replacement rate has a significant impact on the mechanical strength of mortar ($P < 0.001$), and the optimal replacement rate of coal gangue is 60 %.

Table 2. Impact analysis of variance of mechanical strength of 28d mortar

Group	Sum of squares	Degree of freedom	Mean square	F	P
Inter-group	105.441	2	52.721	248.530	< 0.001
Intra-group	1.909	9	0.212	–	–
Total	107.351	11	–	–	–

3.2.2. Effects of water-binder ratio

The effect of water-binder ratio on the mechanical strength of mortar is shown in Fig. 6. At 7d, the flexural strength of mortar raises first and then decreases with the

increase of W/B, and the compressive strength increases.

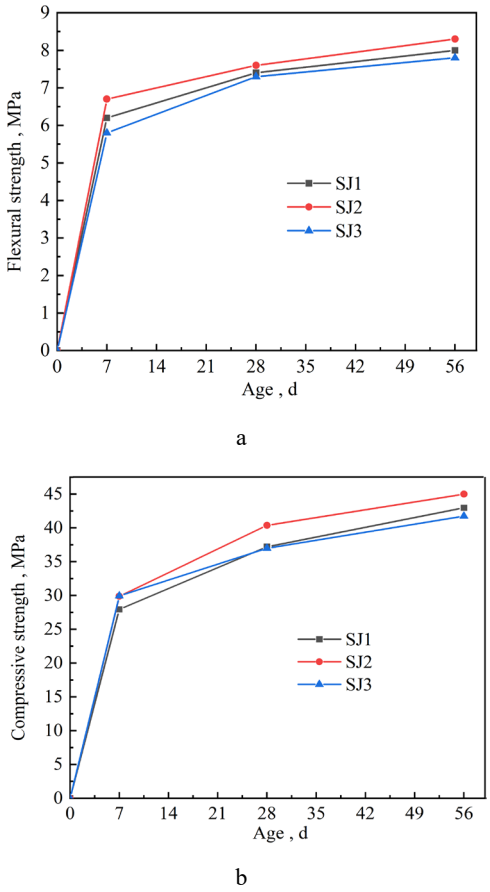


Fig. 6. Effect of water-binder ratio on the mechanical strength of mortar: a – flexural strength; b – compressive strength

The flexural strength of mortar of SJ1, SJ2 and SJ3 groups was 6.2, 6.7 and 5.8 MPa, and the compressive strength was 27.9, 29.8 and 29.9 MPa, respectively. With the extension of curing age, the influence of W/B on the flexural strength of the mortar is basically unchanged, but the compressive strength decreases with the increase of W/B. At 28d, the flexural strength of SJ2 was 7.6 MPa, which was 2.7 % and 4.1 % higher than that of SJ1 (7.4 MPa) and SJ3 (7.3 MPa), respectively. The compressive strength was 40.4 MPa, 9.2 % higher than that of SJ1 and SJ3 (37.0 MPa). When maintained to 56d, the mechanical strength of SJ2 was still the best, with its flexural and compressive strength up to 8.3 and 45.0 MPa, respectively, which are 3.8 % and 4.7 % higher than that of SJ1 and are 6.4 % and 7.7 % higher than that of SJ3. In the case of the same material, the strength of mortar is restricted by workability, which good workability determines the strength growth trend and level after hardening [22]. The consistency of the fresh mortar of SJ1 is 60mm, which is 13 mm less than that of SJ2 (73 mm), resulting in the strength of SJ1 being lower than that of the SJ2 group. The large W/B will consume a lot of water in the mixing of mortar, reducing the compactness of the mortar, thus making the mortar specimens produce more internal pores, leading to the development and expansion of internal capillary channels [23], significantly affecting the production of interface microdefects and bonding performance, thus reducing the strength of mortar [18, 19].

Variance analysis for the 28d mechanical strength of three mortar groups was conducted, as shown in Table 3. It is indicated that the F value is 641.360, $P < 0.001$, and the model is statistically significant, so the difference of W/B in mortar strength is highly statistically significant. Considering that the mortar strength of the SJ2 group performs well in each age, so the optimal W/B is 0.65.

Table 3. Variance analysis of water-binder ratio on 28 d mechanical strength of mortar

Group	Sum of squares	Degree of freedom	Mean square	F	P
Inter-group	28.797	2	14.399	641.360	< 0.001
Intra-group	0.202	9	0.022	–	–
Total	28.999	11	–	–	–

The dosage of water reducer was selected as 0.8 %, 1 % and 1.2 % of the cementing material, respectively, to prepare WJ1, WJ2 and WJ3 three groups of mortar specimens, studying the effect of different dosages of water reducer on the mechanical strength of spontaneous combustion coal gangue mortar, and test the flexural and compressive strength at different ages. The results are shown in Fig. 7.

3.2.3. Effects of water reducer

At 7d, the mechanical strength of the mortar raises with the increase of the dosage of the water reducer. The flexural strength of WJ1, WJ2 and WJ3 was 5.1, 6.5 and 6.8 MPa, and the compressive strength were 26.8, 30.1 and 32.4 MPa, respectively. This is due to the side chains of polycarboxylic molecules of early strength plasticizer are long and the main chains are relatively short. The side chain length is much larger than the main chain, and the distance between the side chains is also greater than ordinary polycarboxylic based water reducer 24, which has a strong steric hindrance and dispersion effect. In addition, the long molecular side chains can also push water into the cement particles to ensure the normal hydration of cement. At the same time, polymers formed by carboxylic groups in the main chain have great hydrophilicity [26], which provides conditions for the continuous hydration of cement and ensures that cement hydration will not be hindered, that is, the less delayed effect of polycarboxylic plasticizer on cement hydration, the greater the early strength of mortar. With the extension of age, the flexural and compressive strength decreases with the increase of the water-binder ratio. At 28d, the flexural strength of WJ2 group is 7.6 MPa, which is 13.4 % and 8.6 % higher than that of thr WJ1 (6.7 MPa) and WJ3 (7.0 MPa), and the compressive strength is 40.4 MPa. Compared with WJ1 (34.7 MPa) and WJ3 (39.4 MPa), the increase was 16.4 % and 2.8 %, respectively. At 56d after demoulding, the flexural strength of WJ2 is 8.3 MPa, 16.9 % and 13.7 % higher than WJ1 (7.1 MPa) and WJ3 (7.3 MPa), and compressive strength of 45 MPa, 13.1 % and 7.9 % higher than WJ1 (39.8 MPa) and WJ3 (41.7 MPa). The water reducer used in the test has a certain effect of air entraining admixture, excessive use will make the gas content of the mortar too high, resulting in many holes inside the mortar, reducing the compactness of the specimens, leading to the late strength of mortar specimens reduced.

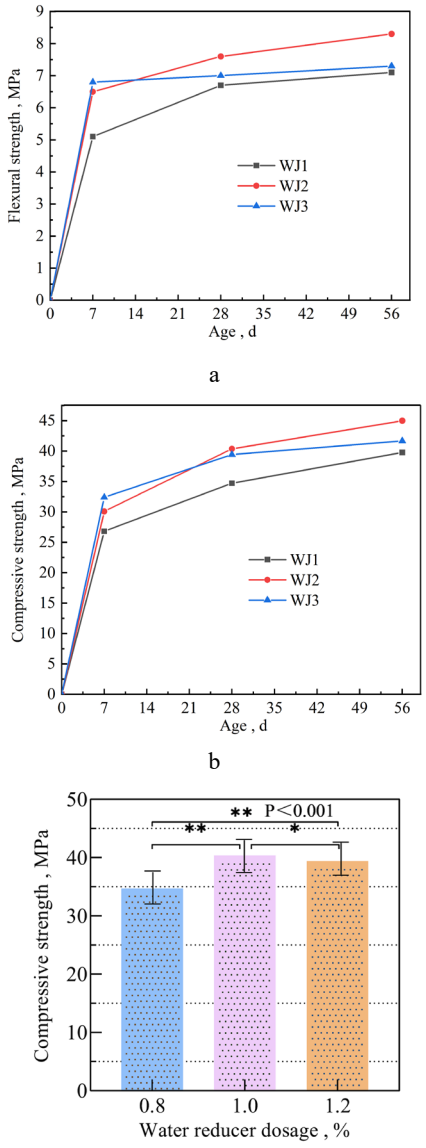


Fig. 7. Effect of water reducer on the mechanical strength of mortar: a – flexural strength; b – compressive strength; c – significance analysis of 28d compressive strength

Significance analysis for 28d mechanical strength of three groups of mortar was conducted, as shown in Fig. 7 c. This result shows that significance $P < 0.001$, mortar strength changes stably, and the difference of the dosage of water reducer on the mechanical strength of mortar is highly significant. Due to the mortar strength of WJ2 having the maximum value, the optimum dosage of admixture is 1 % of the cementitious materials.

3.3. Anti-frost resistance of hardened mortar

Fig. 8 shows the effect of the freezing-thawing cycle on the anti-frost resistance of mortar. This result shows that the mass and strength loss rate of the mortar increases with the raise of gangue replacement rate and water-binder ratio, while increasing the dosage of water reducer can reduce the mass and strength loss rate of mortar. After 5 freeze-thaw cycles, the anti-frost resistance of GS1, SJ1 and WJ3 were the best, with all mass loss rate of 0.1%, the strength loss rates were 1.52 %, 2.37 % and 2.04 %, GS4, SJ3 and WJ1 was the worst, with all mass loss rate of 0.13 % and strength loss rate of 4.64 %, 4.51 % and 4.03 %. After 25 Freeze-thaw cycles, the anti-frost resistance of GS1, SJ1 and WJ3 is the best, with mass loss rate was 0.31 %, 0.25 % and 0.4 %, the strength loss rate was 3.74 %, 5.34 % and 5.01 %.GS4, SJ3 and WJ1 was the worst, with mass loss rates of 0.79 %, 0.5 % and 0.69 %, and strength loss rates of 12.67 %, 12.03 % and 10.99 %.

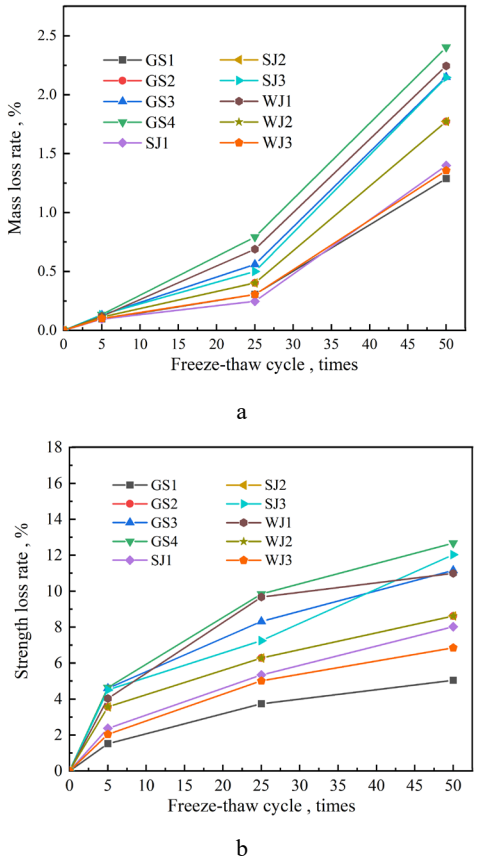


Fig. 8. Effect of the freezing-thawing cycle on anti-frost resistance of mortar: a – mass loss rate; b – strength loss rate

After 50 Freeze-thaw cycles, GS1, SJ1 and WJ3 have the best anti-frost resistance with mass loss rates of 1.29 %, 1.4 % and 1.36 %, and strength loss rates of 5.04 %, 8.02 % and 6.85 %. GS4, SJ3 and WJ1 had the worst anti-frost performance, mass loss rates of 2.4 %, 2.15 % and 2.24 %, and strength loss rates of 12.67 %, 12.03 % and 10.99 %. Nevertheless, the anti-frost performance of spontaneous combustion coal gangue mortar in each group can still meet the requirements, according to the Chinese Standard JGJ 70-2009 (mass loss rate ≤ 5 %, strength loss rate ≤ 25 %).

With the freezing-thawing cycle, the surface of gangue mortar specimens becomes rough, and particles fall off gradually. For mortar with the same mix proportion, when the number of freezing-thawing cycles is less, the cohesion of gangue aggregate and cement slurry decreases less, the mortar structure is dense, and the water infiltration is less, so that cracks in mortar specimens develop slowly. With the increase in the number of freeze-thaw cycles and the development of cracks, the mortar structure becomes loose, and the water infiltrating into the mortar becomes more,

which seriously weakens the bond performance of cement slurry and aggregate, resulting in the mass and strength loss rate of the mortar specimens becomes larger. From the perspective of the performance of aggregate, gangue has large porosity, stronger water absorption and higher moisture content compared with manufactured sand. In the freezing-thawing cycle, there is more free water in the internal void of gangue, water cooling and freezing, the volume begins to expand, forming expansion pressure on the aggregate pore wall and destroying the internal structure of mortar [27, 28]. Anti-frost resistance of gangue is less than the mechanized sand. Therefore, as the replacement rate of gangue increases, the anti-frost resistance of the mortar test piece is weaker.

4. CONCLUSIONS

To make full use of solid waste gangue in engineering, gangue is used instead of manufactured sand in M30 masonry mortar. The effects of gangue replacement rate, W/B and water reducer dosage on fluidity, apparent density, water retention and mechanical properties after hardening of fresh mortar were analyzed. In addition, the anti-frost resistance of gangue mortar was tested by freeze-thaw cycle test. This study is helpful to determine the relationship between the mechanical strength of gangue and experimental variables and provide theoretical guidance and technical support for the commercial application of gangue mortar. The main conclusions of this study are as follows:

1. The apparent density of fresh mortar is gradually decreased with the increase of gangue replacement rate, the W/B and water reducer dosage. With the increase of gangue replacement rate, the fluidity of fresh mortar decreases, but with the increase of W/B and water reducer dosage, the fluidity increases. With the increase of gangue replacement rate, water retention raises, while the increase of W/B makes water retention decrease, and the increase of water-reducing agent makes water retention increase first and then decrease.
2. Spontaneous combustion gangue aggregate completely replacement manufactured sand can prepare the masonry mortar to meet the use requirements of grade M30, while the part replacement aggregate preparation mortar can obtain a higher mechanical strength, and its 28d compressive strength is greater than the design requirements of grade M35 masonry mortar.
3. The flexural strength of the mortar specimen increases first and then decreases with the increase of the water-binder ratio 7d after demoulding, and the compressive strength increases. With the extension of age, the influence trend of W/B on the flexural strength of mortar is basically unchanged, while the compressive strength decreases with the increase of W/B. When the W/B is 0.65, the corresponding mortar strength is better, and the mortar strength prepared is greater than the test strength of M30 grade masonry mortar, which meets the use requirements.
4. The flexural and compressive strength of mortar specimens in the early stage increased with the increase of water reducer dosage, while the mechanical strength in the late stage decreased with the increase of water reducer dosage. When the water reducer dosage is 1 % of the cementitious material, the corresponding mortar strength is better, lower, or higher than the dosage will reduce the mortar strength.
5. The anti-frost resistance of spontaneous combustion gangue mortar is better, and the anti-frost resistance of mortar prepared by completely replacing manufactured sand with gangue aggregate meets the requirements of the standard. With the decrease of gangue replacement rate and W/B, mortar can get better anti-frost resistance, while the increase of water reducer dosage will decrease the anti-frost resistance.

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