



Modeling and experimental study of multiple factors on mechanical strength of iron sand modified cement mortars

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HIGHLIGHTS

- Effects of five factors on iron sand modified cement mortars (ISCM)' mechanical strength were studied.
- The influence degree of multiple factors on mechanical strength for ISCM was analyzed.
- The overall mechanical strength of modified cement mortar mixed natural iron sand is the best among the three cement mortars.
- New prediction models between mechanical properties and multiple factors were developed and analyzed.

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ABSTRACT

To figure out how multiple factors affect iron sand modified cement mortar (ISCM)'s mechanical properties, the influence of the water-cement ratio, sand-cement ratio, river sand-iron sand ratio, density, and age on its mechanical properties were analyzed by compressive and flexural tests. Then, the influence degree of multiple factors on mechanical strength is studied by gray correlation theory. The results showed that the water-cement ratio has the most significant influence on mechanical strength. Afterwards, gray target theory is applied to evaluate the mechanical strength rank of three kinds of ISCM. The results showed the overall mechanical properties of natural iron sand modified cement mortar rank the best. Finally, new prediction models for mortars' compressive and flexural strengths are systematically proposed and compared with two existing models. The results show that the proposed models have more agreements with experimental values.

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1. Introduction

Thermal conductive cement mortar is widely used in civil engineering, petrochemical engineering and so on. Among them, carbon fiber [1–3], graphite [4–6] and other metal thermal conductive materials [7,8] are added into the cement mortar to improve its thermal conductivity. It has been proved that the thermal conductivity of cement mortar can be greatly improved by this kind of thermal conductive material [1–8]. However, the effect of this kind of thermal conductive material on the mechanical properties of cement mortar cannot be ignored, because cement mortar's mechanical properties directly affect its application area and effect. Therefore, it is of great significance to study the mechanical properties of cement mortar with mixed heat conductive materials.

The addition of heat conductive material has a positive and negative effect on the composite's mechanical properties. For example, Garcés [9,10] studied the changes in mechanical properties of calcium aluminate cement mortars and Portland cement mortar with added carbon fibers. The results showed that the amount of fibers added to the mix, water/binder ratio, and curing time determined the compressive and flexural strengths of the mix [9], and the addition of small amounts of carbon fibers to the calcium aluminate cement mortars increases the strength of mortar significantly [10]. Dawood [11] found hybridization of fibers in the quantities 1.5% steel fibers + 0.25% palm fibers + 0.25% Barchip fibers improved cement mortar's compressive, flexural and splitting tensile strength significantly. Demirboğaç [12,13] did studies about cement paste with natural sand content and the effect of silica fume and blast furnace slag on its thermal conductivity and compressive strength. The results showed that silica fume had a decreasing effect on thermal conductivity and compressive strength of cement paste with natural sand content.

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In engineering, the thermal conductivity material which can increase the mechanical strength of mortar is preferred. Metal thermal conductive materials can greatly improve the mechanical strength of cement mortar [11]. While metal slag's characteristics like metal mixture content [14,15], particle fractions [16] and preparation methods [17] have significant influence on mortar's mechanical properties. For example, Ouda [14] studied the mechanical properties of cement mortar mixed with various percentages of iron slag. The results showed that the strength properties of mixtures increased significantly upon replacing sand partially by iron slag. Saha [15] researched the effect of ferronickel slag substitute natural sand content in cement mortar on compressive strength. The results showed that the compressive strength of the hardened mortar specimens increased with the increase of ferronickel slag up to 50% and then declined with further increase of ferronickel slag. Zhang [16] researched the influence of particle fractions of slag powder on the compressive strength of slag cement and Portland cement. The results showed that the volume fraction of particles 5–10 μm had a maximum effect on the mortar compressive strength of slag cement at 7 days and the volume fraction of particles 10–20 μm had a maximum effect on the mortar compressive strength of slag cement at 28 days. J. Rosales [17] studied the mechanical behavior of mortars mixed with stainless steel slag waste which was prepared by different treatments. This study showed that replacing up to 20% of cement with crushed stainless steel slag waste is recommended.

However, research on mechanical properties of thermal conductive cement mortar still needs to be enriched and improved. Firstly, graphite, steel fiber and carbon fiber are not suitable for large-scale use in the field of civil engineering due to its high cost. Secondly, the mechanical strength of the thermal conductive cement mortar mixed with different proportions of heat conduction materials is influenced by many factors. Each factor has a different degree of influence on its mechanical strength. Therefore, it is profound for mix proportion design, preparation and optimization of thermal conductive cement mortar to research the influence degree of multiple factors. Finally, there are few researches on mechanical prediction model between thermal conductive cement mortar's mechanical strength and multiple factors, especially the relationship between its flexural strength and multiple factors. In a word, iron sand, because of its low cost and high thermal conductivity characteristic, are chosen as heat conductive material to add into cement mortar. This study aims to experimentally investigate the effects of multiple factors of three kinds of cement mortars mixed with iron sand on their mechanical properties. The first mortar is composed of natural iron sand, cement, and water (NCW). The second is composed of pure iron sand, cement, and water (PCW). The last is composed of pure iron sand, river sand, cement and water (PRCW). Meanwhile, the correlation analysis between the multiple factors (the water-cement (W/C) ratio, sand (river sand + iron sand) -cement (S/C) ratio, river sand-iron sand (R/I) ratio, density, and age) and mechanical properties (compressive and flexural strengths) were conducted by experiments and mathematical methods. Their correlation degrees were calculated with gray theory. Finally, three kinds of cement mortars will be evaluated by gray target theory. The cement mortar with optimal mechanical properties will be found. The mechanical prediction models are systematically proposed and compared with two existing models.

2. Experiments

2.1. Source materials

The cement used in this study was the 42.5-grade ordinary Portland cement (P. O 42.5). River sand (RS), natural iron sand (NIS), and pure iron sand (PIS) are used as aggregates in mortar mixtures. The characteristics of sand are listed in Table 1. The

Table 1
Characteristics of sand.

Sand type	Particle size(mm)	Apparent gravity(g/cm^3)	Iron content
RS	0.25–0.5	2.68	–
NIS	0.075–0.15	3.70	59.8%
PIS	<0.075	4.37	81%

NIS is processed and obtained with a simple magnet separator from the lower reaches of a sand river, as shown in Fig. 1(a). The percentage of iron in the NIS is 59.8%, while the rest is river sand and impurity. The PIS is produced by an iron mine in Lu'an city of China after professionally processing, as shown in Fig. 1(b). The percentage of iron in the PIS is 81%, and the rest is mineral powder and impurity. The mixing water is tap water. RS mixed with PIS is shown in Fig. 1(c).

2.2. Mix proportions

To analyze the influence of multiple factors (W/C ratio, S/C ratio, R/I ratio, density, and age) on iron sand modified cement mortar, three types of cement mortars were prepared in the tests. Specifically, one is composed of natural iron sand, cement, and water (NCW); another is composed of pure iron sand, cement, and water (PCW); the third one is composed of pure iron sand, river sand, cement and water (PRCW). Each specimen with a specific mix proportion is shown in Table 2. For NCW, R/I ratio is the ratio of river sand content to iron content in the natural iron sand.

3. Test methodology

All the specimens with the size of 40 mm \times 40 mm \times 160 mm used for different tests were prepared according to ASTM C 348 [18], as shown in Fig. 2 (a). The three specimens for each of 33 mix proportions were molded to test the flexural and compressive strength at the age of 28 days. Also, the specimens for mix proportion 1, 10 and 19 were molded at various ages (3, 7, 28, 63 and 90 days) to test flexural and compressive strength. All of the specimens should be maintained in curing boxes at a constant temperature ($20 \pm 1^\circ\text{C}$) and humidity (not less than 90%). The specimens total is 270.

3.1. Compressive tests

Compressive tests were conducted for specimens according to ASTM C 349 [19], as shown in Fig. 2(b). The pressing surface was on the sample's lateral side with 40 mm \times 40 mm area. 33 different groups of specimens were prepared for compressive test, three specimens in each group. The average value for each group is obtained.

3.2. Flexural tests

All specimens were tested in the laboratory, taken directly from the storage container. Flexural tests for different mix proportions were carried out on the long surface of trabecular specimens using a bend tester according to ASTM C 348 [18], as shown in Fig. 2(c). The broken specimen of the flexural test is shown in Fig. 2(d). Similar to the compressive tests, the average values of flexural strength values were obtained.

4. Results and discussion

The method of controlling variable was adopted to research how multiple factors (W/C ratio, S/C ratio, R/I ratio, density, and age) influenced the mechanical properties (compressive and flexural strengths). Therefore, the ages of the specimens are all specified as 28 days when the test values are used to study the effect of W/C ratio, S/C ratio, R/I ratio and density on the mechanical properties. S/C ratio will be kept at 2.0 in analyzing the effect of W/C ratio on the mechanical properties. W/C ratio will be kept at 0.60, which is

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