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Activity of calcined coal gangue fine aggregate and its effect on the mechanical behavior of cement mortar

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HIGHLIGHTS

- Aggregate the dissolubility ion and its surface area ratio as an index of activity.
- Analyzed under different calcination temperature fine aggregate XRD patterns.
- Influence of different active aggregate of mortar strength through microscopic test.
- Effect of different coal gangue fine aggregate activity on mortar strength.

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ABSTRACT

In order to reveal the influence of coal gangue aggregate activity on the mechanical properties of the mortar, to promote coal gangue fine aggregate in concrete mortar application, this paper in view of the calcined coal gangue aggregate carried out ion dissolution test (ICP), construction of the coal gangue aggregate ion dissolution amount and its surface area ratio as a quantitative index of activity, namely activity index of *Ka*. The different fineness modulus, different curing age of concrete mortar carried out compressive strength and flexural strength test, and the hardening of cement mortar combined with microscopic test results, in order to analyze the influence of coal gangue aggregate activity on the mechanical performances of mortar. Experimental results show that, under the same calcination temperature and surface area of coal gangue fine aggregate with the same ion dissolution ability, coal gangue fine aggregate index activity increases with the gradual decrease of fineness modulus. A higher activity index of coal gangue fine aggregate mortar corresponds to higher compressive strength and flexural strength of mortar in the improved macro mechanical properties; the early strength of mortar has clear characteristics.

1. Introduction

Coal gangue is produced in the process of coal mining, sorting, and processing of solid wastes, accounting for approximately 10% of coal production [1,2]. A large number of simple piles of coal gangue negatively affected the environment. With the mass production of coal gangue, one way to use it is to replace ordinary sand by coal gangue fine aggregate mixed into concrete, which is called coal gangue fine aggregate concrete. The active SiO_2 and Al_2O_3 components in the coal gangue, with cement hydration products at a certain degree of secondary hydration reaction, can facilitate a more thorough hydration process and improve the microstructure and macro mechanical properties of cement mortar [3–5]. For example, Salguero et al. [6] have used coal gangue to replace part of the fine aggregate, the experimental tests indicate the fitness of the new material for the purposed application, namely regarding resistance to compression, it reached higher compressive resistance (56.44 MPa), comparatively with the conventional concrete (maximum at 41.03 MPa). Therefore, the active influence of concrete mortar on the mechanical properties of concrete mortar is analyzed to scientifically and effectively evaluate the activity of coal gangue fine aggregate. Coal gangue utilization has become a major topic related to social and economic development. Many scholars have conducted extensive and in-depth research on coal gangue activity [7–10]. The coal gangue ash evaluation method has the following categories: strength evaluation, evaluation, and electrochemical evaluation of microscopic structure. Many researchers have investigated and practiced these three

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methods, but the evaluation system has matured only through the quantitative analysis of coal gangue powder material. Application for fineness modulus of large sand body material is not possible. Thus, a deeper quantitative evaluation of the activity of coal gangue fine aggregate and building activity as well as its relationship with concrete mortar strength is needed.

This study is based on the engineering application and research background of gangue fine aggregate for the 500, 600, 700, 800, and 900 °C high-temperature calcination. Coal gangue by calcination and its phases, which involve a series of changes, contains a large number of active components that can improve the activity of coal gangue [11–14]. XRD diffraction experiment is conducted to analyze the coal gangue fine aggregate activity as it changes with calcination temperature. Then of calcined coal gangue in materials by ion dissolution test (ICP) and specific surface area determination (BET) test, with coal gangue aggregate surface ion dissolution amount and its surface area ratio, as an active quantitative index, activity index (*Ka*), in order to quantitative assessment of price of coal gangue aggregate activity. ICP (Inductively Coupled Plasma), is a kind of test method used for determination of element concentration, by ICP emission spectrometer, the sample in the plasma excitation, make specific wavelengths of light that is emitted element under test instrument can analyze the elements of the emission spectrum peak intensity, compared to the mass number of standard curve and standard solution of quantitative analysis of the elements in the solution [15]. BET, it is a standard test method for measuring solid specific surface area, surface tester is based on nitrogen adsorption, with helium or hydrogen as the carrier, two gases mixed in certain proportion, to achieve the specified relative pressure, and then through the solid material, on the basis of the absorption peak area, can be calculated under the pressure of adsorption, which according to BET formula to calculate the specific surface area [16].

At last, combined with the environmental scanning electron microscopy (SEM) analysis, the influence of different activity index of coal gangue fine aggregate on the compressive strength and flexural strength of concrete mortar was analyzed.

2. Experimental section

2.1. Coal gangue physical and chemical properties

The coal gangue from Xuzhou mining area was tested for non-spontaneous combustion. Black or dark gray color indicates higher hardness rate.

Using ordinary concrete to building sand, stone quality inspection standard test method, to 700 °C high temperature calcined coal gangue core drilling, core samples of the cylinder diameter and height are of 50 mm, after press testing, we can see gangue axial compressive strength of 55.2 MPa, therefore, 700 °C of calcined coal gangue content of ordinary concrete aggregate demand [17–19]. The main chemical composition of coal gangue was analyzed by X-ray fluorescence spectrometry (XRF) (Table 1). The coal gangue is composed of SiO_2, Al_2O_3, iron, calcium, and magnesium oxide. The indicators of coal gangue utilization were compared according to the condition $SiO_2 + Al_2O_3 > 80\%$. The chemical composition characteristics are rich in siliceous or aluminum characteristics. The chemical composition of coal gangue is used as fine aggregate concrete [12,20,21].

2.2. Coal gangue fine aggregate activity analysis

Gangue mineral composition analysis was conducted using X-ray diffractometer. The coal gangue in 500, 600, 700, 800, and 900 °C temperature was calcined under 2 h and rapidly cooled to room temperature. The diffraction experiment was conducted according to the diffraction condition 325 to grind the coal gangue into powder. The test conditions were the following: 40 kV X-ray tube accelerating voltage, 30 mA electric current, Cu target, K radiation, 250 mm goniometer radius, 0.6 mm divergence slit, 8 mm scattering slit, 0.1 s/step scanning speed, and 0.018450 sampling interval (step). Calcined coal gangue fine aggregate phase was characterized by types of changes.

Table 1
Coal gangue main chemical composition.

Chemical composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Content (%)	59.78	29.35	1.44	0.68	0.51	0.08	1.76

2.3. ICP ion dissolution test and determination of specific surface area

2.3.1. ICP ion dissolution test

The standardized ion dissolution test [22], compared with the standard test, adopts the scaling method, which is the configuration of NaOH solution (1 g of gangue sample corresponding to 100 mL NaOH solution). Several gangue fine aggregate samples were weighed with a corresponding 1 mol/L of NaOH solution in a container. This task was performed after the samples were sealed in a constant temperature box set at 40 °C for 3 h and then filtered; the filtrate was used as preservation seal. Full spectrum direct reading plasma emission spectrometer was used to detect the filtrate Al^{3+} and Si^{4+} ion leaching, particularly coal gangue silicon–oxygen tetrahedron and aluminum–oxygen tetrahedron depolymerization ability [23–25].

2.3.2. Determination of specific surface area (BET)

Surface area analyzer was used to measure the adsorption characteristics of fine aggregate, thereby performing a surface area analysis. The analyzer was equipped with three sample measurement channels. Each channel had independent pressure sensors that measured the three samples simultaneously. Coal gangue fine aggregate samples must be dry and have granularity below 5 mm, as well as specific surface area greater than 0.01 m^2/g.

The first gangue fine aggregate was the ICP ion dissolution test. After test completion, the gangue fine aggregate was dried and its surface area was determined using the BET analyzer. The test results are shown in Tables 2 and 3.

2.4. Make and strength test specimens

Portland cement using P.O42.5 cement and tap water. The original fresh coal gangue was crushed, sorted, and calcined. The fineness modulus after the screening was 1.9, 2.7, and 3.4 coal gangue fine aggregate, which were classified under fine, medium, and coarse sand specifications, respectively. Proportion, quality fixed water, and cement have a fine aggregate ratio of 1:2:4. The specimen size has length × width × height of 40 mm × 40 mm × 160 mm according to the standard strength detection method, molding cement mortar specimens [26]. The cement mortar specimens were made in a curing chamber to the required standard curing age.

2.5. Microstructure analysis (SEM)

Environmental scanning electron microscopy is the standard method of raising broken specified support age-hardened cement mortar test pieces. The selected test center of a 5 mm cube small is fragmented after drying. Other procedures terminate the hydration. Moreover, selected pieces were placed in a vacuum-coating machine for evaporation on a layer of gold conductive film, and then under the scanning electron microscope observation of its microstructure.

3. Results and discussion

3.1. Fine aggregate activity evaluation

Coal gangue aggregate has an irregular granular body. The subsequent test analysis showed that coal gangue set material in the calcination process mainly exhibited a change of surface mineral composition. These changes in concrete, mortar, and cement occurred as a reaction to hydration. The fine aggregate surface active group was divided into two parts. In ICP ion dissolution testing, the group of hydroxyl ions with NaOH solution has a chemical reaction on the fine material on the surface of the SiO_2 and Al_2O_3 activity component. Therefore, the set of coal gangue in material active substances are distributed in the surface, internal active

Table 2
Ion dissolution of different fineness modulus values under the same calcinations temperature.

Calcination temperature (°C)	Fineness modulus	Specific surface area (m^2/g)	Al (mg/L)	Si (mg/L)
700	1.9	9.4799	126.76	130.11
700	2.7	6.7314	74.44	76.23
700	3.4	4.6464	46.81	48.07