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Characteristics of the fired bricks with low-silicon iron tailings

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HIGHLIGHTS

- Producing fired brick utilized iron tailings and fly ash instead of traditional clay and shale resource.
- Performance of bricks was good and promising.
- The temperatures and content of fly ash on the properties of bricks were studied.

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ABSTRACT

This paper studies the feasibility of utilizing low-silicon iron tailings for production of eco-friendly fired bricks. In order to improve the bricks quality, we add different proportions of fly ash to the raw materials. Compositions were prepared with additions of 5 wt.%, 10 wt.%, 15 wt.% and 20 wt.% fly ash in tailings. Initially, the iron tailings and fly ash were characterized by their chemical compositions, X-ray diffraction and particle size. The brick pieces were prepared and fired, and then the sintering shrinkage, weight loss on ignition, water absorption, apparent porosity, compressive strength, phase compositions and microstructure of final fired samples were investigated. Results indicated that the firing temperature and fly ash proportion significantly influenced the bricks properties. With different proportions of fly ash added to the bricks, the physical properties at temperatures from 900 °C to 1000 °C were well conformed to Chinese Fired Common Bricks Standard (GB/T5101-2003). The main mineral phases of the product were hematite, quartz, anorthite, diopside and anhydrite, which were principally responsible for the mechanical strength of bricks.

1. Introduction

Bricks have been as the major construction and building material for several thousand years all over the world. Conventional production of bricks usually utilizes clay and shale as the raw material and requires high temperature (900–1000 °C) kiln firing [1]. Construction industry generally uses large amounts of clay bricks in most of buildings and the demand for bricks is expected to be continuously rising [2]. Thus a large number of clay and shale resource will be used every year. The continuous extraction of clay as brick manufacturing raw material causes substantial depletion of the non-renewable resources. In many areas of the world, there is already a shortage of clay and shale material for production of the conventional bricks. To protect the clay resource and develop eco-friendly building materials, some countries such as China have forbidden producing and using normal clay solid bricks in many cities and have been actively advocating the use of solid wastes for making building materials to realize the phase-out of common clay solid bricks [3–5]. Owing to the flexibility of the brick composition, different types of waste have been successfully incorporated into fired clay bricks by previous researchers, even in high percentages [6–19].

With the rapid development of the iron and steel industry, a large amount of iron ore tailings are generated each year. According to statistic in the year 2006, in China, the amount of all tailings, which had been discarded and stacked, was estimated to be 59.7 billion tons, out of which approximately one third of the total tailings are due to the iron tailings, but there are still increasing within the range of over 300 million tons per year [20,21]. Because iron tailings is mainly composed of silica, alumina, calcium, iron, manganese, sulfur, phosphates and few heavy metal compositions, which are similar in composition to the natural clay that they can be used as a clay substitute to produce bricks [22].

Using the iron tailings as raw materials to produce construction bricks would be a good option. Because it not only conforms to the ecological policy of China, but also can maximally realize utilization

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of the solid waste. This paper studies the possibility of utilizing low-silicon iron tailings with a small quantity of fly ash to produce eco-friendly sintered bricks. And the bricks physical and mechanical properties were investigated.

2. Materials and methods

2.1. Raw materials

The iron tailings used in the study were obtained from the iron concentration plant of the Zhenjiang Mineral Co. Ltd. in Jiangsu, China. The fly ash, which presented in fine powders with gray color, was taken from a thermal power plant in Nanjing. The iron tailings and fly ash were dried at 105 °C for 12 h in an electric oven thermostat in order to remove moisture. After drying, the iron tailings were crushed and grounded, in order to obtain a uniform particle size for subsequent use. The grain size distribution of the iron tailings and fly ash were performed by the laser particle size distribution analyzer (Bettersize, BT-9300S).

The plasticity index of iron tailings is defined as the difference in water content between the liquid and plastic limits. The liquid and plastic limits were determined through the Model ZY-1 Cone Liquid-limit Test Apparatus.

The surface area of the iron tailings was identified by BET method using the surface area and porosimetry analyzer (Applictio, V-Sorb 2800p). The chemical composition of raw materials was determined through XRF (Philips X-ray diffractometer PW1710). The loss on ignition (LOI) was determined according to LOI = $(W_d - W_c)/W_d \times 100$, where W_d is the weight of the dry sample at 105 °C, and W_c is the weight of the calcined sample at 950 °C during 20 min.

The mineralogical composition of the main raw materials was identified by XRD (Bruker D8 Advance) using Cu (Ka) radiation (40 kV, 40 mA). The morphologies of specimens were examined by scanning electron microscopy (Quanta 250FEG) at operating voltage of 5 kV.

The thermal analysis of the iron tailings was performed in a Netzsch STA 449F3 thermal analyzer. Raw materials were heated from room temperature (20 °C) to 1250 °C at a rate of 15 °C/min in N_2 atmosphere.

2.2. Experimental methods

Iron tailings and fly ash were mixed by different weight ratio. Mixture proportions were presented in Table 1. The mixtures containing iron tailings with the fly ash were firstly mixed for 10 min in a blender, and then necessary amount of water (about 10% by mass) was added to the mixture for the production of semi-dry molded brick samples and mixed for another 10 min. Homogenized mixtures in the blender were pressed into cylinder (diameter of 40 mm, length of 40 mm) for producing brick specimens. Semi-dry mixtures were pressed under a pressure of 20 MPa using a hydraulic press (WE-30B). The shaped samples were left in ambient conditions for 12 h for desiccation. And then the specimens were dried in an oven at 35 °C for 12 h and then at 105 °C for 8 h to decrease moisture content. The dried specimens were fired in a laboratory electrical furnace at a rate of 2 °C/min from room temperature to the desired firing temperature (900 °C, 950 °C and 1000 °C, the temperatures most frequently used in the brick industry) and holding for 2 h at the desired firing temperature to achieved strength. After firing, bricks were cooled to room temperature by natural convection inside the laboratory electrical furnace.

2.3. Characterization of fired brick samples

The technological properties of the fired samples such as compressive strength, water absorption, weight loss on ignition, apparent porosity, sintering shrinkage and bulk density have been tested to determine the optimum preparation condition for sintered bricks. The compressive strength, water absorption and bulk density of the sintering bricks must reach to the requirement of the Fired Common Bricks Standard (GB/T5101-2003) [23] for construction bricks. Weight loss on ignition meant the weight loss of bricks during the sintering process. Weight loss on ignition was calculated from Eq. (1). Sintering shrinkage was calculated from Eq. (2). According to the Test Methods for Wall Bricks (GB/T2542-2003) [24], water absorption values were determined from mass differences between the as-sintered and water saturated samples (soaking in cold water for 24 h), and it was calculated from Eq. (3). Bulk density test was obtained in accordance with standard procedure described in Test Methods for Wall Bricks [25], and it was calculated from Eq. (4). Apparent porosity was calculated from Eq. (5). Because the specimens were smaller than common bricks, the compressive strength of sintered bricks was measured via a computer controlled automatic pressure testing machine (SANS CMT5105), and it was calculated from Eq. (6). In order to get accurate test results, four samples were made to determine these properties of sintered bricks in this research.

$$\text{Loss on ignition} = (W_{bs} - W_{as})/W_{bs} \quad (1)$$

where W_{bs} is for weight of specimens before sintering and W_{as} is for weight of specimens after sintering.

$$\text{Sintering shrinkage} = (V_{bs} - V_{as})/V_{bs} \quad (2)$$

where V_{bs} is for volume of specimens before sintering and V_{as} is for volume of specimens after sintering.

$$\text{Water absorption} = (W_{asw} - W_{as})/W_{as} \quad (3)$$

where W_{asw} is for weight of specimens after soaking in water for 24 h.

$$\text{Bulk density} = W_{as}/V_{as} \quad (4)$$

where W_{as} is for weight of specimens after sintering and V_{as} is for volume of specimens after sintering.

$$\text{Apparent porosity} = (W_{asw} - W_{as})/(W_{asw} - W_{su}) \quad (5)$$

where W_{su} is for suspended weight of each sample while suspended in water.

$$\text{Compressive strength} = F_b/S_a \quad (6)$$

where F_b is for force of breaking specimens and S_a is for force area of specimens.

Table 1
The proportions of the mixtures for the formulations (wt.%).

Formulations	Iron tailings	Fly ash
F0	100	0
F5	95	5
F10	90	10
F15	85	15
F20	80	20

3. Results and discussion

3.1. Characterization of the raw materials

The particle size distribution curves were shown in Fig. 1. The results revealed that the samples presented a wide range of particles sizes. The curve of the iron tailings presents a monomodal distribution, with more than 96% of the particles with equivalent diameter smaller than 50 μm. The median particle size (d50) of the iron tailings was 6.98 μm. The median particle size (d50) of the fly ash was 41.96 μm. And the particles with equivalent diameter smaller than 50 μm was more than 55%. Therefore, the iron tailings and fly ash were very fine and there is no need for grinding or other particle size processing.

The main chemical analysis and the loss on ignition of the raw materials used were shown in Table 2. It can be seen that the main constituents of the iron tailings were the oxide forms of silicon, aluminum, calcium and iron (36.48% SiO_2, 11.67% Al_2O_3, 16.85% CaO and 18.58% Fe_2O_3, respectively). Comparing to traditional clay materials [22], the content of the oxide forms of calcium and iron is too high, but the content of the oxide forms of silicon is too low. The main constituents of the fly ash were the oxide forms of alumina and silicon (48.28% and 29.84%). Loss on ignition of the fly ash is 1.22%, which is associated with the presence of unburned carbon and the elimination of some hydrated in the fly ash. As we can see, the fly ash contains a sufficient amount of the oxide forms of silicon and aluminum and lesser extent of the oxide forms of calcium and iron. So the addition of the fly ash can make up for the disadvantages of the iron tailings as the raw materials of the sintered bricks.

The plasticity index of iron tailings was 14.9. So the iron tailings can be classified as a plastic material. The BET surface area of the iron tailings is 9.58 m^2/g. The particulate density of the iron tailings and fly ash were 3.11 and 2.04 g/cm^3.

The X-ray diffraction patterns of the iron tailings and fly ash were shown in Fig. 2. According to the X-ray diffraction patterns, the major mineral phases of the iron tailings were quartz (SiO_2), clinochlore ($(Mg,Fe)_6(Si,Al)_4O_{10}(OH)_8$) and calcite ($CaCO_3$) and the minor phases were hematite (Fe_2O_3) and pyrite (FeS_2) (Fig. 2a). The high Fe_2O_3 content in iron tailings is due to the presence of