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Synthesis of a ceramic tile base based on high-alumina fly ash

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HIGHLIGHTS

- A ceramic tile base was prepared by using high alumina fly ash as main raw material.
- Effects of adding high alumina fly ash and sintering temperature were investigated.
- Macro and micro properties of the samples were systematically investigated.
- The study provides a new method for efficiently utilizing the high alumina fly ash.

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ABSTRACT

To effectively utilize the industrial waste of high-alumina fly ash (HAFA), a ceramic tile base was successfully synthesized by the ceramic sintering process. In this research, the influence of HAFA addition and sintering temperature on properties were investigated. The results showed that the presence of ferruginous and calcareous minerals in HAFA decreased the inversion temperature of densification. Moreover, the optimum parameters were obtained at the sintering temperature of 1300 °C for 2 h with 70% HAFA, 15% clay and 15% quartz. In this research, the highest flexural strength reaches 67 MPa, and the corresponding bulk density and apparent porosity values are 2.43 g/cm^3 and 0.13%, respectively.

1. Introduction

Nowadays, power industry plays an important role in the development of energy in China; and it provides strong support for the development of China's national economy [1]. As reported by the Outline of Mid-long Term Energy Development in China (2004–2020), the electric power production was still dominated by thermal power for a considerable period of time. Moreover, a large amount of fly ash was emitted by thermal power plants. These enormous amounts of fly ash, produced during the development processes, not only occupied vast expanses of land, but also caused serious problems to environment [2–3]. From the yearly report of resources integrated use in China (2014), the annual production of fly ash in 2013 was about 580 million ton. According to statistics, 60% of the fly ash was used for creating cement, concrete, bricks, wallboards, etc. However, the remaining 40% of fly ash was obsoleted in ash ponds. In this way, the fly ash took up worthful earth resources, and a portion of fly ash may cause air pollution owing to their low density. As a result, the recycling of fly ash is gaining importance as the need for environmental protection increases.

Besides, there is a special solid waste, high alumina fly ash (HAFA), which acquired from the burning of high-alumina coal. This type of coal resource mainly distributed in China's northwest, which is one of the most significant energy foundations of China. According to statistics, the emission quantity of HAFA was roughly 30 million tons annually, and the whole resource quantity was up to 15 billion tons in China [4]. Considering the unusual alumina content of more than 40% in HAFA, it can be taken as a renewable and worthful mineral resource [5]. At this stage, the utilization of HAFA was mainly concentrate on alumina extraction with method of soda-lime sintering or other techniques [6–7]. However, grave environmental troubles were led to by these methods, so it can't be large-scale application due to its high-cost. Thus, an environment-friendly recycling method of HAFA must be researched.

Recently, much research has been focused on the utilization of general fly ash [8–12], including soil amelioration, ceramic industry, catalysis and support for catalysis, adsorbents for removal of various pollutants, depth separation, zeolite synthesis and valuable metals recovery. Given this solid waste was produced in huge quantities, a method that can bulk consume this waste is particu-

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larly attractive. In this case, there are some researches indicated that HAFA can be used to produce building materials, mine reclamation, and concrete pavement construction [13–15] by referring to the utilization of general fly ash. Besides, it has huge potential for the utilization as ceramic raw material because of the similar constituents to the ceramic contents. Although it would be attractive to substitute HAFA for costly raw materials in preparation of ceramic, the presence of impurities in HAFA limited it used in preparing ceramic materials due to the appearance of final product. Thus, it's necessary to change the utilization method for recycling HAFA. The application of HAFA in ceramic tile base has the vast development potential. In this way, the disadvantage of HAFA products can be covered by the multi-layer, and greatly enhanced the additional value of products. Compared to the traditional ceramic, this method has increased the production cost, but within an acceptable range. Taken together, due to the increase of value in product and the reuse of solid waste (HAFA), this method has a big potential. Moreover, it can be used in the structural material, composite material and glazed tile base, etc.

In this background, by absorbing and integrating the previous research results, a ceramic tile base that environment-friendly prepared from HAFA as the main raw material is reported. Moreover, the strength properties of the ceramic tile base are associated with the composition of raw materials, and the HAFA is not suitable for production of ceramic tile base because of the high contents of alumina [16–17]. Hence, some sintering agents needed to add in raw materials. In this work, the ceramic tile bases that contain 30–80% HAFA have been successfully prepared. The effects of different additions of HAFA and other raw material on properties of samples were researched. Furthermore, the impacts of different sintering temperatures on ceramic tile base were also investigated.

2. Experimental procedure

2.1. Characterization of raw materials

In this work, three raw materials were selected to obtain green body: HAFA, clay, and quartz, respectively. The HAFA produced from thermal power plant was obtained from an open storage in Shuozhou city, Shanxi province, in China. The clay and quartz also came from local resources. Moreover, all of raw materials were crushed in a mortar and then dried in a lab dryer at 110 °C for 24 h. For these raw materials, X-ray fluorescence (XRF) was used to detected the chemical compositions of raw materials, and the crystalline phases in raw materials were investigated by X-ray diffraction (XRD, D/max 2550, Rigaku, scanning grate: 8°/min, scanning range: 10–80°) in this research.

The chemical composition of these raw materials was given in Table 1, and the crystalline phases of HAFA and clay are given in Fig. 1. It is observed from Table 1 that fly ash mainly contained 39.78 wt% Al_2O_3 and 42.85 wt% SiO_2, while consists of a small quantity of CaO and Fe_2O_3. Furthermore, high content of Al_2O_3 (42.55 wt%) and SiO_2 (37.20 wt%) contained in clay that locally produced. Moreover, it can be seen from Fig. 1 that, in HAFA, the major crystalline phases are Mullite ($Al_6Si_2O_{13}$, #01-079-1454) and Quartz (SiO_2, #01-075-0443), while in clay, the major mineral phases are Kaolinite ($Al_2Si_2O_5(OH)_4$, #01-075-1593) and Boehmite (AlO(OH), #01-083-2384).

2.2. Preparation of green tile samples

According to the need of mix raw materials well together, all raw materials were wet-ball-milled for 12 h with agate balls as ball-milling medium using a planetary ball milling (PBM) machine at a constant speed of 400 rpm in the proportion as shown in Table 2, and the chemical composition of green samples were shown in Table 3. The content of Al_2O_3 and CaO increased with the addition of HAFA.

After complete drying in 110 °C for 24 h, the mixture powder was uniformly mixed with distilled water in an alumina mortar for molding. In this work, two kind of sample were prepared (cylinder: 37 mm in diameter and 8 mm in thickness, rectangular: 150 mm × 10 mm × 10 mm rectangular) at a pressure of 45 MPa. Finally, the green tile samples were placed in muffle furnace, and then heated to various final temperatures in the range of 1000–1500 °C. The sintering atmosphere was air atmosphere. The heat-

Table 1
The chemical composition of raw materials (wt%).

wt%	SiO_2	Al_2O_3	K_2O	Na_2O	Fe_2O_3	TiO_2	CaO	MgO	LOI
HAFA	42.85	39.78	0.48	0.13	2.18	1.35	4.60	0.62	4.43
Clay	37.20	42.55	0.40	0.09	0.81	1.48	3.45	2.20	11.32
Quartz	96.39	1.11	0.42	0.21	0.25	0.20	0.59	0.13	0.54

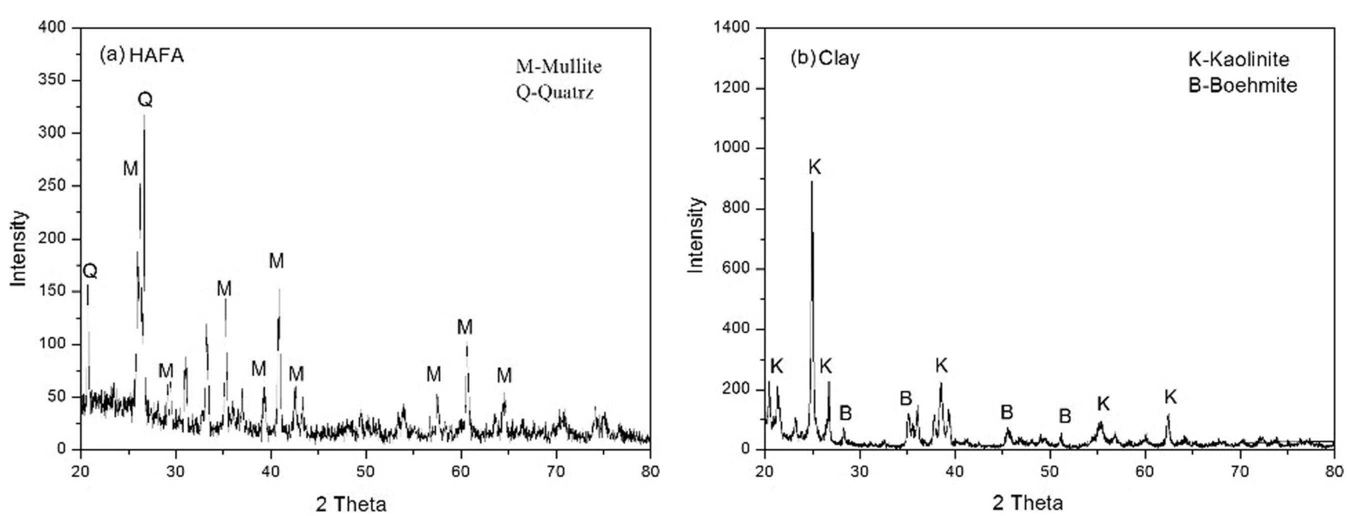

Fig. 1. X-ray diffraction pattern of fly ash and clay.