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Preparation of novel ceramic tiles with high Al_2O_3 content derived from coal fly ash

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HIGHLIGHTS

- A novel alumina-rich ceramic system was proposed to fabricate the ceramic tile.
- Macro-properties and microscopic structures of the samples were investigated.
- New ceramic system exerts great influences on the performance of the sample.
- The study provides deep insights into the usage of alumina-rich industry solid waste.

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ABSTRACT

In order to take full advantage of coal fly ash (FA) with high alumina content, the present study proposed a novel method to fabricate the ceramic tile by using FA as the main raw material. The influences of FA content on the macro-properties and microscopic structures were systematically investigated. Results revealed that the rupture modulus of the sample containing 60 wt.% FA and 4 wt.% quartz can reach 51.28 MPa at 1200 °C. Furthermore, its corresponding water absorption capacity, apparent porosity, linear shrinkage are 0.47%, 1.1% and 13.51%, respectively, which all exceed the requirements for porcelain tiles. The excellent properties may be ascribed to the proposed alumina-rich ceramic system, which exerts great influences on the crystalline phase composition and the densification process of the sample. This study definitely paves the way for the efficient utilization of FA and provides deep insights into the usage of other alumina-rich industry solid waste.

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1. Introduction

Ceramic tile, one of the most frequent-used building materials, has been widely developed to meet the demand in construction considering that the annual newly built residences could reach 2 billion square meters in China. The fabrication of ceramic tile requires a large number of raw materials, for instance, 1 square meters of ceramic tile needs 20 kg of raw materials according to the previous study [1]. Hence, the demand for raw materials would be striking. Faced with the shortage of high-quality raw materials and the rising cost, it is therefore in urgent need to seek alternative raw materials with high availability.

To realize this target, researchers have made great efforts to prepare ceramic tiles using industrial waste, such as steel slag, coal fly ash and coal gangue [2–11]. For example, Erol et al. [2] prepared ceramic materials from FA with no additives; Olgun et al. [3] developed ceramic tiles from FA and tincal ore waste; Lü et al. [6] studied the environment-oriented ceramic membrane supports with coal gangue and bauxite; while Wei et al. [7] recycled steel slag and harbor sediment into construction materials. These previous studies are significant, because they not only relieve the shortage situation of traditional materials, but also verify the feasibility of the method by using industrial waste as an alternative raw material of ceramic tile. Moreover, the utilization of FA is conducive to facilitate the enhancement of ceramic properties. In particular, He et al. [10] produced glass-ceramics sintered from FA and the solid parts contain more than 74 vol.% cordierite and mechanism property is higher than 30 MPa. Zhang et al. [11] proposed a useful choice to recycle FA from power plants to manufacture glass-

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Table 1
The chemical composition of the raw materials.

Content (wt.%)	SiO_2	Al_2O_3	K_2O	Na_2O	CaO	Fe_2O_3	MgO	TiO_2	S	LOI
Fly ash	41.97	39.90	0.501	0.197	6.41	1.96	0.600	1.20	3.15	3.64
Clay	34.96	36.57	0.385	0.088	0.492	0.824	0.221	1.47	–	24.38
Feldspar	68.60	17.50	7.74	3.98	0.530	0.408	0.171	0.0358	–	0.83
Quartz	91.30	4.47	1.76	1.19	0.424	0.166	0.152	0.0125	–	0.44

ceramic which was considered harmless by using the toxicity characteristic leaching procedure (TCLP) method. However, all of these studies focused on the ceramic preparation with certain solid wastes, but the corresponding ceramic system was rarely proposed, which limited their potential applications to other solid waste utilization.

Before the starting of this study, the analysis and investigation of the characteristics of FA are required. FA is the by-product of coal combustion in thermal power plants [12,13] and the annual generation has reached 580 million tonnes in China by 2015 [14–16]. Although approximately 69% of FA are comprehensively utilized [17], there are still a large amount of FA untreated and dumped in landfills or ash ponds, which not only occupies valuable land resources but also causes serious environment problems, such as water pollution, air pollution, disruption of ecological cycles and environmental hazards [18–20]. Therefore, it is necessary to develop useful methods to solve this problem.

Meanwhile, it is worth to note that the composition of FA is complex and its physicochemical properties depend on the type of raw coal and the combustion conditions [15,21]. In China, there are many alumina-rich FA in Inner Mongolia and Shanxi province [14], in which Al_2O_3 content is as much high as 40%. However, the traditional ceramic tile belongs to SiO_2-Al_2O_3-Na_2O (K_2O) ternary system with the Al_2O_3 content in the range of 15–25 wt.% and CaO content less than 3 wt.% in the raw materials mixture. For this reason, it is necessary to broaden the preparation area of the traditional ceramic. Thus, the present study is motivated to apply alumina-rich ceramic system (SiO_2-Al_2O_3-CaO-K_2O) to prepare high-quality ceramic tiles for the usage in special circumstances.

In this paper, a novel alumina-rich ceramic system was proposed to fabricate the ceramic tile using FA as the raw materials in combination with the traditional raw materials. Both macro-properties (linear shrinkage rate, water absorption capacity, apparent porosity, rupture modulus) and microstructure analysis were systematically investigated. The proposed new ceramic system would not only realize the efficient utilization of alumina-rich FA, but also lay the foundation for the use of other alumina-rich waste.

2. Experimental procedure

2.1. Materials

The FA is supplied by a thermal power plant, which is located in Shuozhou City, Shanxi province in China. Other raw materials including clay, feldspar and quartz, were derived from one region close to Shuozhou City. The chemical compositions of these materials were analyzed by X-ray fluorescence (XRF) and the results are shown in Table 1. For FA, the main compositions are SiO_2, Al_2O_3, CaO and Fe_2O_3. Clay mainly consists of 34.96% SiO_2 and 36.57% Al_2O_3. In feldspar, SiO_2, Al_2O_3, K_2O and Na_2O are the major compositions. The main component of quartz is SiO_2.

The crystalline phases of the raw materials determined by X-Ray Diffraction (XRD) are shown in Fig. 1. XRD analysis results show that the FA is a heterogeneous material, and it is composed of glassy phases (about 58%) and parts of crystalline phases are quartz, mullite and a few of gypsum. This may be explained by the generation procedure of FA. The FA particles solidify rapidly while suspended in the flue gases. The major consequence of the rapid air cooling is that some minerals have no time to crystallize, i.e., part of FA exists with glassy phases. Nevertheless, some refractory phases in FA do not melt, and maintain the same crystal structure.

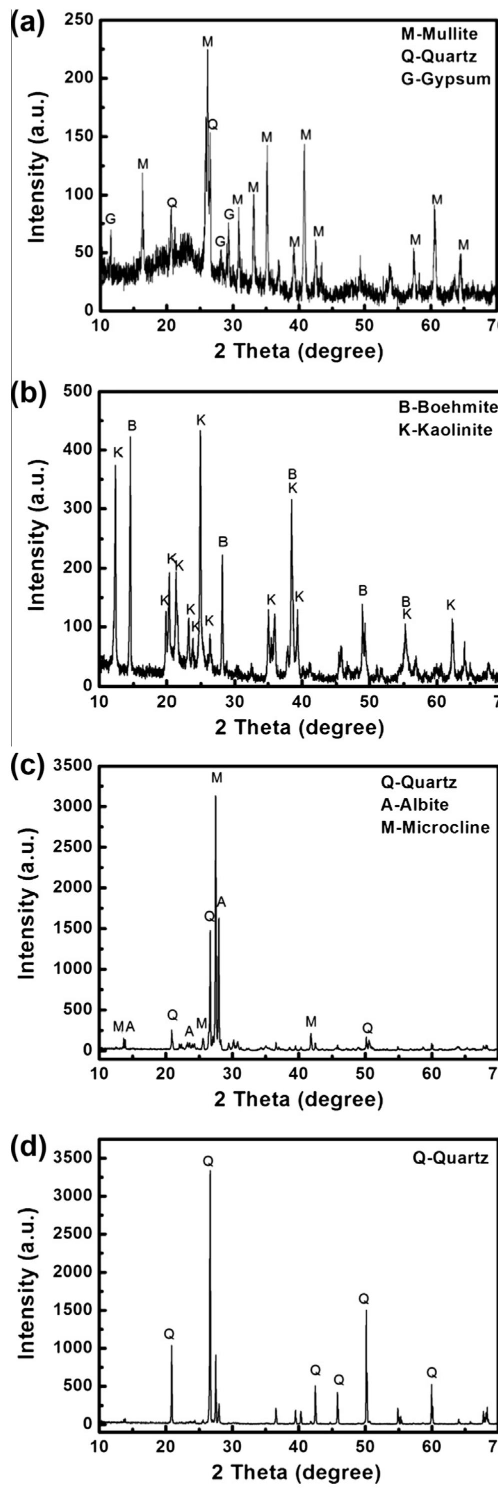

Fig. 1. XRD patterns of the different raw materials. (a) Fly ash, (b) Clay, (c) Feldspar, (d) Quartz.

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