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# Preparation and properties of porous ceramic aggregates using electrical insulators waste

Nana Xu[a], Shujing Li[a,b,*], Yuanbing Li[a], Zhengliang Xue[a], Lin Yuan[b], Jinlong Zhang[b], Lei Wang[b]

[a]The State Key Laboratory of Refractories and Metallurgy, Department of Materials Science and Engineering, Wuhan University of Science and Technology (WUST), Wuhan, 430081, PR China

[b]Anhui Ruital New Material Technology Co., Ltd., Hefei 242300, PR China

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**Abstract**

In this paper, porous ceramic aggregates were prepared by electrical insulators waste (EIW). Effects of sintering temperature and content of EIW on the aggregates' properties such as bulk density, and apparent porosity, total porosity, and cold crushing strength were investigated. With increasing sintering temperature and content of EIW, bulk density and cold crushing strength of the aggregates increased, apparent porosity and total porosity decreased. Based on these results, total porosity of specimens in group B sintered at 1200 °C is 62.0%, cold crushing strength is 35.3 N, and thermal conductivity is 0.165 W/(m K) at 300 °C. Comprehensive properties of specimens can be optimized by adjusting sintering temperature. Meanwhile, strength variation resulted from the combined effects of phase transformation and matrix densification under different sintering temperatures.



*Keywords:* Electrical insulators waste; Aggregates; Properties; Microstructures

## 1. Introduction

Electrical insulators, which were produced by the mixtures of $SiO_2$ and $Al_2O_3$ under heavy pressure, were widely used for power transmission due to high strength and excellent insulation performance [1]. In recent years, the demand of electrical insulators has increased sharply due to the rapid development of power industries [2,3]. Subsequently, plenty of electrical insulators were eliminated to become ceramics waste, most of which were not recycled. The reservation of electrical insulators waste (EIW) increased million tons every year. Such a situation caused serious environment pollution and wasted resources [4,5]. The treatment of EIW has become a particularly severe problem in most countries [6].

Porous materials were very attractive due to their controllable porosity and excellent heat insulation for numerous applications such as thermal insulators, substrates for catalyst, filter systems and building materials [7]. A wide variety of porous materials have been prepared by using several raw materials such as ceramics [8], glasses [9], cements [10] and organic materials [11]. It was a particularly severe problem to reutilize waste materials for the fabrication of porous materials and reduce consumption of natural resources.

In this paper, EIW were used as a cheap raw material for the preparation of porous ceramic aggregates in order to take advantage of $SiO_2$ and $Al_2O_3$ component effectively and provide low cost porous ceramic aggregates for light-weight castable. Bulk density, apparent porosity, thermal conductivity, phase evolution, pore size distribution and microstructure combined with thermodynamics calculation were investigated.

## 2. Experimental procedure

### 2.1. Materials and specimens preparation

The particle size of all starting materials such as EIW (Hefei, Anhui Ruitai New Material Technology Co. Ltd., PR China), fly

*Corresponding author at: The State Key Laboratory of Refractories and Metallurgy, Department of Materials Science and Engineering, Wuhan University of Science and Technology (WUST), Wuhan, 430081, PR China.
Tel.: +86 13554079817.
*E-mail address:* lsjwust@163.com (S. Li).

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ash (Wuxi, Power plant of Wuxi, PR China) and clay (Fujian, PR China) were −0.1 mm. The chemical compositions of the starting materials are shown in Table 1. Sawdust was used as pore forming agent and the average particle size ($d_{50}$) of sawdust was nearly 0.21 mm which was examined by a laser particle size analyzer (Mastersizer 2000, Malvern Instruments Ltd., UK).

EIW, fly ash, clay and sawdust were mixed to prepare homogenous mixtures according to different batch compositions shown in Table 2. During the pelletization process, binders such as water and polyvinyl alcohol solution were sprayed into the mixture. Depending on the rotating speed and tilt angle of the pan pelletizer, fresh pellets of different sizes were obtained. Fresh pellets were dried at 110 °C for 24 h, and then fired at 1100, 1200 or 1300 °C for 3 h.

### 2.2. Thermodynamics calculation

In order to study the phases and compositions after firing at varied temperatures, thermodynamic software FactSage 6.1 was used in thermodynamics calculation [12,13]. FT oxid and Fact slag databases were chosen for the simulation of thermal chemical reaction, and the results of calculation were verified by experiments.

In the calculation, the total mass of mixture was assumed as 1000 g. According to chemical and batch compositions shown in Tables 1 and 2, the highest content of $SiO_2$ was in group C. So it was chosen for the following calculation while polymorphic transformation of $SiO_2$ was complicated during sintering or cooling progress [14]. With increasing sintering temperature, the amounts of different phases and compositions in the reaction simulation are shown in Fig. 1. Liquid phase started to appear at 1125 °C and then increased sharply, but the content of $SiO_2$ and $KAlSi_2O_6$ decreased sharply at this temperature. Meanwhile, amount of mullite phase remained stable, and some traces of $Fe_2O_3$, $Fe_2O_5Ti$ were also detectable.

Table 1
Chemical composition of raw materials (wt%).

| Component (wt%) | $SiO_2$ | $Al_2O_3$ | $K_2O$ | $TiO_2$ | $Fe_2O_3$ | IL |
|---|---|---|---|---|---|---|
| Electrical insulators waste | 70.09 | 24.37 | 2.66 | 0.50 | 1.60 | 0.37 |
| Fly ash waste | 31.87 | 13.98 | 1.01 | 0.37 | 2.40 | 50.0 |
| Clay | 30.99 | 45.98 | 0.71 | 0.10 | 1.82 | 19.10 |

Table 2
Batch compositions (wt%).

| Group | EIW | Fly ash | Clay | Extra additions | | |
|---|---|---|---|---|---|---|
| | | | | Water | Sawdust | Organic bond |
| A | 50 | 40 | 10 | 10–15 | 500 ml/kg | 5–10 |
| B | 60 | 30 | | | | |
| C | 70 | 20 | | | | |

### 2.3. Characterization

Phase compositions of sintered specimens were identified by X-ray diffractometry (X' Pert Pro, Philips, Netherlands). Bulk density and apparent porosity were tested by the Archimedes method in distilled water, while the weight of sintered spherical specimens for the testing was 50 g with the diameter 3–5 mm. True density was tested by Automatic pycnometer (AccuPyc 1330, Micromeritics, American). The test method for cold crushing strength was shown in Fig. 2, the data was calculated from the average value of 30 sintered spherical specimens with a diameter of 5 mm which was measured by using an electronic tensile testing machine (HT-9112, Hung Ta, Taiwan, PR China). Thermal conductivity of the sintered specimens was tested by a tabulate thermal conductivity apparatus (PBDR-02, Precondar, PR China), while 3 sintered specimens with a diameter of 180 mm and height of 20 mm were used for testing. Pore size distribution was determined with the diameter of specimens from 3 to 5 mm by mercury porosimetry (Auto Pore IV 9510, Mike, American). Microstructure was observed by a scanning electron microscope (SEM, JSM-6610, JEOL Company, Japan).

In the following equations, $V_A$, $V_S$ and $V_C$ stand for the volume of apparent pores, solid phase and closed pores; the sum of $V_A$, $V_S$ and $V_C$ is $V$ (Eq. (1)); $\rho_B$ and $\rho_T$ are the bulk density and true density, respectively; Eq. (2) represents the

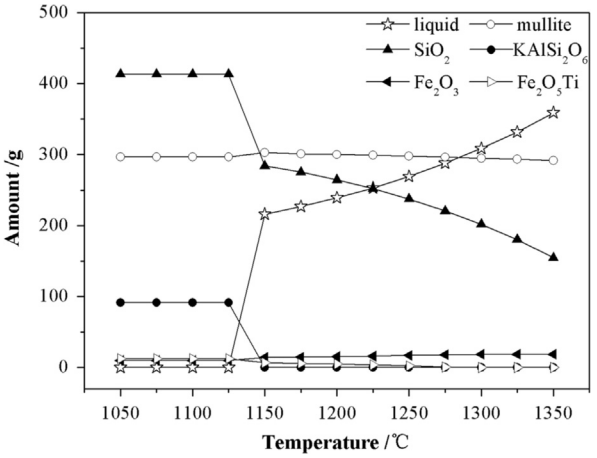


Fig. 1. Amount of different phases and compositions under different temperatures based on thermal calculation.

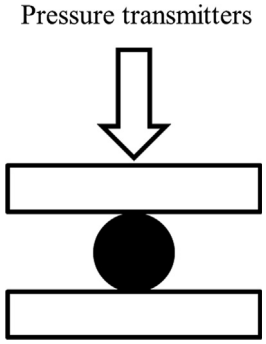


Fig. 2. Schematic diagram of cold crushing strength testing.