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Review

Preparation and characterization of ceramic substrate from tungsten mine tailings

Weizhen Liu, Ting Wu, Zhuo Li, XiaoJun Hao, Anxian Lu *

School of Materials Science and Engineering, Central South University, Changsha 410083, PR China

HIGHLIGHTS

- We explore a new way to reuse tungsten mine tailings: preparing ceramic substrate.
- The changes of microstructure and properties of ceramic substrate are regular.
- The ceramic substrate we prepared shows good physical and chemical properties.
- We have confirmed the best sintering temperature.
- The good performance indicates it possesses market potential and fine application.

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ABSTRACT

In order to effectively utilize industrial wastes, we prepared ceramic substrates successfully by conventional ceramic sintering process using tungsten mine tailings as the main raw material. The properties of the ceramic substrates sintered at different temperatures (from 1000 to 1250 °C) were investigated. The crystalline phases and microstructure obviously changed. The pores appeared when the sintering temperature was above 1200 °C, and ceramic substrates had the densest structure at 1150 °C. The bulk density and powder density both showed first increasing then decreasing with the sintering temperature increasing, and both reached the maximum at 1150 °C, 2.50 g/cm^3 and 2.58 g/cm^3 respectively. The porosity had the minimum, 3.10%, at 1150 °C. The samples also showed good corrosion resistance performance. The changes of the mechanical properties were similar to that of bulk density. The flexural strength and compression strength reached to 138.52 MPa and 1129.36 MPa, respectively, showing good mechanical strength. The good performance of ceramic substrate from tungsten mine tailings indicates it possesses the market potential and fine application.

Contents

* Corresponding author. Tel.: +86 0731 88830351; fax: +86 0731 88877057.
E-mail addresses: liuweizhen1031@163.com (W. Liu), axlu@csu.edu.cn (A. Lu).

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1. Introduction

The huge volumes of industrial waste produced today represent one of the world's greatest environmental problems and the recycling has emerged as a very important environmental issue nowadays due to the diminishing nature resources and the increasing amount of solid wastes. Tungsten tailing, as a tailing from the tungsten mine waste, also has brought some environmental problems, like contaminating soil, water and air in the surrounding areas [1]. These pollutants from mine waste sometimes bring some social problems causing damages, not only to animals and plants, but also to the people health [2,3]. China has the largest tungsten output in the world, accounting for about 84.5% [4]. The tailings from tungsten mine waste have led to large deposits over the years, especially in Hunan, one of the largest production provinces. These deposits present a potential risk of environment pollution and cause serious landscape impacts, thus affecting the life quality of local populations. Considering its hazardous, proper planning should be undertaken to manage these wastes, and how to recycle the tailings is a major issue for us. There have some studies about how to utilize the mine waste recently [5,6].

The researches on the reuse of tungsten mine waste mainly focused on the use of geopolymeric binder; for example, Pacheco-Torgal et al. [7] used tungsten mine waste mud geopolymeric binder as a new cementitious material, finding it had very high early age strength. Pacheco-Torgal et al. also investigated the strength and microstructure [8] and the preliminary hydration products [9] of tungsten mine waste geopolymeric binder. Wang Choi et al. [10] also studied use tungsten mine waste tailings as a substitution material for cement. Castro-Gomes et al. [11] researched the potential reuse of tungsten mining waste, calling it as rock in technical-artistic value added products. They presented experimental and prototype work to study the mechanical and physical characteristics of tungsten mining wastes, and showed that there was a potential for the reuse of them. There are also some studies on the secondary minerals in tungsten mine tailings. Petrunic et al. [12] used TEM finding that oxidized sphalerite and tennantite grains from tungsten mine tailings were encapsulated by secondary coatings. The most abundant coating in each sample was an amorphous or nanocrystalline Fe–Zn–As–O phase. Álvarez-Ayuso et al. [13] studied the arsenopyrite weathering products in mine wastes from abandoned tungsten.

There are lots of differences among the content of tungsten mine tailings from different production regions [14], as showing in Table 1. A number of studies show a great potential for its reuse, but lack of regulation in this field. In this study, authors used tungsten mine tailings from Jiangxi as the main raw material to prepare ceramic substrate, with aluminum oxide and magnesium oxide as additives. Ceramic substrates were sintered at different temperatures to explore the optimal temperature. The properties changes of ceramic substrates were measured by several testing methods to show its practical applications. This is a tentative exploration of preparing ceramic substrates using tungsten mine tailings as main material. It can low costs in current, and may play an important role to eliminate the storage of tungsten mine tailings.

Table 1
The differences among the content of tungsten mine tailings from different production regions (±0.01 wt.%).

Production regions	Xihua Mountain	Jiangxi Ganzhou	Hunan Chuankou	Hunan Shizhuyuan	Guangdong Lechang
SiO_2	82.43	75.15	90.92	46.90	80.65
Al_2O_3	5.76	9.05	3.35	8.84	2.51
Fe_2O_3	1.80	2.40	0.62	2.65	10.38
K_2O + NaO	5.83	5.68	1.18	3.24	2.00
CaO	0.44	1.20	0.59	28.32	0.24
MgO	1.11	0.95	0.03	4.33	0.38
Others	2.63	5.57	3.31	5.72	3.84

Table 2
Chemical composition of tungsten mine tailings heated treatment at 900 °C for 2 h (±0.01 wt.%).

Constituents	Contents
SiO_2	69.57
Al_2O_3	13.13
Fe_2O_3	5.27
K_2O	4.19
CaO	2.44
MgO	2.11
Na_2O	0.74
Other minor oxides	2.55

2. Experimental procedure

2.1. Raw materials and sample preparation

Tungsten mine tailings in the present experiment were from Jiangxi of China, and it was subject to a thermal treatment at 900 °C during 2 h, in order to achieve the dehydroxylated state [15]. The chemical compositions of the heat-treated tailings were determined by X-ray fluorescence analysis (ZSX Primus II, 50 kV-60 mA) and the result was shown in Table 2. The raw materials of preparing ceramic substrate were heat-treated tungsten mine tailings, aluminum oxide (Al_2O_3) (⩾99.9%) and magnesium oxide (MgO) (⩾99.9%). The contents are showed in Table 3. The granular size of raw materials was 1–10 μm, and well mixed.

The samples were prepared by a laboratory uniaxial dry-pressing into disk shapes with a diameter of 50 mm, thickness of 10 mm, using a pressure of 30 MPa. The obtained green specimens were then sintered in an electric laboratory furnace with a heating rate of 3 °C/min. They were firstly treated at 450 °C for 1 h in order to remove the residue water and protect the samples from cracking caused by the uneven thermal distribution. Subsequently, each sintering process was carried out in duplicate at different maximum temperatures, at 1000 °C, 1050 °C, 1100 °C, 1150 °C, 1200 °C and 1250 °C, respectively, and holding for 2 h, to evaluate the effect of this parameter on the characteristics of the ceramic substrates. Natural convection inside the furnace was used for cooling to room temperature. The samples of ceramic substrate were obtained.

2.2. Characterization techniques

X-ray diffraction (XRD, D/max, 2500 model, Rigaku, Japan) was used to investigate the crystalline phases of the samples. The diffractometer was with Cu Kα radiation in the 2θ range from 5° to 80° at 0.02 steps, which operated at 40 kV and 50 mA at a scanning rate of 4°/min. The crystalline phases were identified by matching the peak positions of the intense peaks with PCPDF standard cards.

The microstructure of ceramic substrates samples were examined by the scanning electron microscope (SEM, FEI Quanta-200). The surface of the samples were polished by sand paper and then sputtered with a gold coating. Microstructure could be observed clearly.

The bulk density was measured with helium psychometry. The total porosity was obtained from the bulk density and the powder density using the following equation:

$$\text{Porosity } (\%) = (1 - \text{Bulk density}/\text{Powder density}) \times 100\% \tag{1}$$

The corrosion resistance was measured using the following equation. The samples were immersed in alkaline and acidic solution, respectively, which the solution concentrations were both 0.01 mol/L, and holding 24 h. We weighed the samples masses before and after corrosion. Five samples were measured to take the average value in each experiment.

$$\text{Corrosion resistance } (\%) = m_a/m_0 \times 100\% \tag{2}$$

where m_0 and m_a are the weights of the drying samples before and after corrosion.

The flexural strength and compressive strength were test, using a CS44100 testing machine at a speed of 0.5 mm/min. The samples of flexural strength were machined into 25 mm × 5 mm × 5 mm test bars, and square samples of 12.5 mm length and 5 mm × 5 mm section area were subjected to uniaxial compressive loading. Each result was the average of five measurements.

Table 3
Chemical compositions of the ceramic substrates (±0.01 wt.%).

Raw materials	Tungsten mine tailings	Al_2O_3	MgO
Contents	70.00	20.00	10.00