Available online at www.sciencedirect.com
ScienceDirect
Ceramics International 41 (2015) 1213–1221
CERAMICS INTERNATIONAL
www.elsevier.com/locate/ceramint

Recycling of low-silicon iron tailings in the production of lightweight aggregates

Chuanmeng Yang, Chong Cui*, Juan Qin

School of Materials Science and Engineering, Nan Jing University of Science and Technology, Nan Jing 210094, China

Received 10 July 2014; received in revised form 10 September 2014; accepted 10 September 2014
Available online 21 September 2014

Abstract

This paper reports the result of the investigation on manufacturing lightweight aggregate by the mixtures of the low-silicon iron tailings, fly ash and powdery quartz sand. The raw materials were characterized by chemical compositions, X-ray diffraction and particle size. The investigation was performed in a laboratory scale to assess the effects of the composition of the mixtures and the sintering conditions on the properties of the artificial lightweight aggregates. The effects of the composition of the mixtures and sintering temperatures on the bloating index, loose bulk density, apparent density, water absorption and compressive strength were determined. All the mixtures studied in the paper presented a bloating potential at high temperatures. The bloating index of all the samples is greater than 1, so all types of aggregates were expanded aggregates. The products obtained were lightweight aggregates. The microstructure and the phase composition of the lightweight aggregates were analyzed by scanning.electron microscopy (SEM) and X-ray diffraction (XRD). The main mineral phases of the products were hematite, quartz and anorthite, which were principally responsible for the mechanical strength of the aggregates. The analysis of microstructures with SEM revealed a vitrified matrix and an extended formation of isolated and closed pores.

Keywords: Iron tailings; Bloating; Lightweight aggregates; Characteristics

1. Introduction

Tailings refer to waste materials of beneficiation processes. With the increasing demand for iron and steel and commensurate processing of iron ore, the proportion of iron tailings is growing faster. Few reuse and large storage of iron tailings have resulted in negative impacts on society with occupying land, and the management of the iron tailings has brought about heavy economic burden to the mining enterprises [1–4]. In recent years, comprehensive utilization of tailings has been receiving considerable attention by most countries in the world, and many studies have been reported [5–7], for example, backfilling, preparation of building materials and recovery of valuable elements. Currently, the iron tailings is mainly reused as raw materials in producing building materials [8–11], such as these fields of fired bricks, foamed concrete, autoclaved bricks and cementitious materials. Using tailings to produce building materials not only can realize zero-emission of tailings wastes, but also would offer a new alternative raw material for building industry.

Lightweight aggregates (LWAs) are porous and granular materials with a apparent density typically not exceeding than 2.00 g/cm^3 or with a loose bulk density not exceeding than 1.20 g/cm^3 [12]. Artificial LWAs can be formed in a ceramic process in which materials that have the ability to expand are rapidly heated at high temperature. Two conditions are necessary to achieve an appropriate expanded material: (a) it should contain sufficient gas producing substances, and (b) on heating, pyroplasticity should occur simultaneously with the formation of gas, which can be brought about by various reactions [13]. The chemical composition of the expansive clay is as followed: SiO_2 48–79%; Al_2O_3 8–25%; (Fe_2O_3 + CaO + MgO + K_2O + Na_2O) 8–26% [15]. The raw materials for LWAs can be of different origins, for example, waste

*Corresponding author.
E-mail addresses: yangchuanmeng@126.com (C. Yang), cuichong@njust.edu.cn (C. Cui).

http://dx.doi.org/10.1016/j.ceramint.2014.09.050
0272-8842/

materials like sewage sludge, reservoir sediments, waste glass, fly ash, mining wastes, etc. or natural raw materials like clay and shale [14–21]. Due to their typically low density, good thermal and acoustic insulation, and good fire resistance properties, LWAs have become a focus of interest. In fact, they are an essential component in a variety of building materials such as prefabricated structural units, lightweight concretes, especially in high-rise buildings, as well as track ballasts and road coatings, along with bituminous materials and geotechnical applications [22].

The high temperature sintering process was used in this study to prepare the LWAs employing the low-silicon iron tailings, fly ash and powdery quartz sand as the raw materials. The objective of this research is to characterize the properties and microstructure of LWAs produced by the mixtures and the effects of the chemical compositions and sintering temperatures on the physical properties of the LWAs 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. Powdery quartz sand was supplied by Anhui Mining Limited Company, China, which was broken tails of quartz sand used to produce glass. All these samples were oven dried at 105 °C for 24 h until reaching constant weight. After drying, the iron tailings and quartz sand were crushed and ground, in order to obtain a uniform particle size for subsequent use. The grain size distribution of the iron tailings, fly ash and powdery quartz sand were performed by the laser particle size distribution analyzer (Bettersize, BT-9300S).

The plasticity index of iron tailings was 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 chemical composition of raw materials was determined through XRF (Philips X-ray diffractometer PW1710). The loss on ignition (LOI) was determined according to $\text{LOI} = (W_d - W_c)/W_d \times 100$, where W_d is the weight of the dry sample at 105 °C, and Wc is the weight of the calcined sample at 950 °C during 20 min.

The mineralogical composition of the main raw materials was identified by X-ray diffractometer (Bruker D8 Advance) with CuKα radiation ($\lambda = 1.542$ Å) at an accelerating voltage of 40 kV and a current of 40 mA.

2.2. LWAs manufacturing

The weight ratio of the iron tailings, fly ash and powdery quartz sand was adjusted and determined according to the Riley's diagram so that the elemental compositions of the mixtures were within Riley's foaming composition range [15].

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

Formulations	Iron tailings	Fly ash	Powdery quartz sand
F1	30	40	30
F2	30	50	20
F3	30	60	10

On the basis of the results obtained in the characterization of raw materials, different raw materials and proportions of them were presented Table 1.

The raw materials were completely mixed, then, the mixtures were poured into a self-designed pelletization disc to produce pellets. A controlled amount of water was added until the mixtures consistency allowed formation of approximately spherical, 5–10 mm diameter pellets. The green pellets were dried for 48 h at room temperature and then were put in an oven at 105 °C for 48 h. The dried specimens were sintered in a laboratory electrical furnace at a rate of 10 °C/min from room temperature to 900 °C and then at a rate of 25 °C/min from 900 °C to the desired sintering temperatures (1210 °C, 1220 °C and 1230 °C) and holding for 15 min at the desired sintering temperatures. After sintering, the specimens were cooled to room temperature by natural convection inside the laboratory electrical furnace.

2.3. Physical properties of the LWAs

Bloating index, 1 h water absorption, 24 h water absorption, loose bulk density, apparent density and compressive strength were employed to characterize the quality of the sintered pellets.

Bloating index was expressed as the ratio of volumes before and after sintering, following the equation Bloating index = d2/d1, where d1 and d2 are the diameters of pellets before and after sintering, respectively.

Loose bulk density, apparent density and water absorption were tested according to China Lightweight Aggregates and Test Methods (GB/T 17431.2-2010) [23]. Loose bulk density was calculated as W1/V1 ratio, where W1 is the weight of the aggregates contained in a recipient with a volume V1. Apparent density is the relationship between the mass of a sample of aggregates after sintering (W2) and the volume these aggregates occupy in water (V2). Apparent density was calculated as W2/V2 ratio. Water absorption determined from the weight difference between the sintered and water saturated samples (immersed in water for 1 h and 24 h). The values of 1 h water absorption and 24 h water absorption were obtained using the following formulas:

1 h water absorption $= (W_{asw1} - W_{as})/W_{as}$, where W_{as} is for weight of specimens after sintering; W_{asw1} is for weight of specimens after soaking in water for 1 h. 24 h water absorption $= (W_{asw24} - W_{as})/W_{as}$, where W_{asw} 24 is for weight of specimens after soaking in water for 24 h.

Compressive strength (S) of individual pellets was calculated according to Yashima et al. [24]: $S = (2.8P_c)/(\pi X^2)$, where