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# Effect of the ratio of components on the characteristics of lightweight aggregate made from sewage sludge and river sediment

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ABSTRACT

Previous studies shown that sewage sludge and river sediment can be used to produce lightweight aggregate (LWA). Control of the ratio of components in the LWA production process is important. In this study, we investigated the effect of mass ratio (K) of basic ($Fe_2O_3$, CaO, and MgO) and acidic ($SiO_2$ and $Al_2O_3$) oxides on the characteristics of LWA. The studies show that LWA with lowest water absorption, the lowest solubility in hydrochloric acid and the highest grain density, the highest bulk density can be obtained when K in the range of 0.15–0.3, the properties of LWA in accordance with the standard of GB/T 17431.2-1998, China. When K was fixed at 0.2, the mass ratio of $SiO_2$:$Al_2O_3$ in the range of 4:1–1:1 and the mass ratio of $Fe_2O_3$:CaO:MgO in the range of 5:2.2:1–1.7:1.9:1 resulted in LWA with the desired physical properties, the maximum compressive strength can reach 17.07 MPa. The heavy metals experiments show that the leaching content (Cd, Cr, Cu and Pb) is closely related to a variation in K ratio, heavy metals can existed as stable crystalline compounds in LWA, and exhibiting excellent heavy metals solidification ability even it subjected to destruction, which indicates that stronger chemical bonds are formed between these heavy metals and the components through heat-induced transformation to the crystalline state. Investigations indicate that K can be a useful parameter to optimize LWA qualities.



## 1. Introduction

It is widely accepted that issues of environmental concern are increasing constantly. The handling of sewage sludge is one of the most significant challenges in wastewater management, as sewage sludge often contains abundant organics, pathogenic bacteria and heavy metals and is detrimental to human health and the environment if not disposed of appropriately (Garcia-Valles et al., 2007; Rio et al., 2006; Seredych and Bandosz, 2007; Werle and Wilk, 2010).

The application of traditional sewage sludge treatment methods such as landfill, incineration and agricultural fertilizer are subject to certain restrictions because of their potential negative effects on the environment or human health (Smith et al., 2009; Fytili and Zabaniotou, 2007; Rio et al., 2006). It is therefore imperative to explore environmental alternatives for the disposal of sewage sludge. Some new methods have been investigated e.g., wet oxidation, pyrolysis, gasification and co-combustion of sewage sludge with other materials for further use as an energy source (Hamilton, 2000; Khiari and Marias, 2007; Lin et al., 2006; Malkow, 2004; Mun et al., 2009; Murakami et al., 2009). Among these methods, the utilization of sewage in civil and building materials has generated significant scientific interest because of its potential in adding value to the sludge. For example, Cusidó and Soriano (2011) analyzed the transformation of sewage sludge through a ceramization process into a material similar to expanded clays indicated that it can be used in the building industry or in the agriculture industry.

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González-Corrochano et al. (2010) employed sludge and fly ash as raw materials to produce lightweight aggregates with high strength and suggests that it can be used as a lightweight aggregate material in some industrial fields, such as geotechnical applications, prefabricated lightweight structures and lightweight insulating concretes. Others also have reported the development of lightweight ceramic aggregates made from dehydrated sewage sludge, clay, incinerated sludge ash, Calcareous fly ash, spent glauconite, zeolites or municipal solid waste incineration ash (Cioffi et al., 2011; Glinicki et al., 2016; Qi et al., 2010; Franus et al., 2015, 2011). As well as reducing secondary contamination to the environment, the use of sewage in building materials has certain economic benefits (Chen et al., 2010; Chiang et al., 2009; Saikia et al., 2008; Sales et al., 2011; Sorlini et al., 2011).

In our previous investigations, sewage sludge and drinking water sludge have been tested successfully as raw materials for producing ceramisite (Xu et al., 2008, 2009a,b). River sediment and drinking water sludge are all rich in the mineral components (such as $SiO_2$, $Al_2O_3$, $Fe_2O_3$, CaO, and MgO) necessary for generating high quality ceramisite or lightweight aggregate (LWA). River sediment can be seen as one of the main materials required to be mixed with sewage sludge in LWA manufacture.

Control of the component ratios in the LWA production process appears to be important, but the components of sewage sludge and river sediment may differ according to season or district. In this study, we therefore investigated the effect of mass ratio of basic ($Fe_2O_3$, CaO, and MgO) and acidic oxides ($SiO_2$ and $Al_2O_3$) (where $(Fe_2O_3 + CaO + MgO)/(SiO_2 + Al_2O_3)$ is defined as K) on LWA characteristics and examined whether K is a useful parameter in controlling LWA properties. Furthermore, we investigated the effect of $SiO_2$:$Al_2O_3$ (SA) and $Fe_2O_3$:CaO:MgO (FCM) (at fixed K ratio) on LWA characteristics.

## 2. Materials and methods

### 2.1. Materials

Sewage sludge in this study was obtained from the Harbin Wenchang Wastewater Treatment Plant in Harbin. River sediment was obtained from Hejiagou River in Harbin. Chemical characteristics of the sewage sludge and river sediment are shown in Table S1 (Supporting information). Sodium silicate $[Na_2O\cdot(SiO_2)_x\cdot(H_2O)_y]$ with modulus of 3.2 was selected as an additive in LWA production. All oxides $SiO_2$, $Al_2O_3$, $Fe_2O_3$, CaO and MgO with particle sizes below 10 μm were analytical grade and of highest purity.

To investigate the solidification effectiveness of the heavy metals (Cr, Cd, Pb, and Cu) in the sewage sludge and river sediment for LWA production, a solution of heavy metals $K_2CrO_4$, $Cd(NO_3)_2$, $Pb(NO_3)_2$, and $Cu(NO_3)_2\cdot3H_2O$ was added to the raw materials. The contents of Cd, Cr, Cu, and Pb were determined from analysis of activated sludge at different locations in China as shown in Table S2 (Supporting information). The simulated heavy metal concentrations in raw materials (sewage sludge and river sediment mixed at mass ratio 1:1) were: Cd 50 $\mu g\,g^{-1}$, Cr 1000 $\mu g\,g^{-1}$, Pb 1000 $\mu g\,g^{-1}$ and Cu 500 $\mu g\,g^{-1}$.

### 2.2. Methods

#### 2.2.1. LWA preparation

Sewage sludge and river sediment were treated by the air-dry method, then dried at 105 °C until they reached invariable mass before the two sludges were crushed to pass No. 100 sieve (mesh diameter 0.154 mm).

The raw materials were mixed completely first. The mass ratio of sewage sludge:river sediment:sodium silicate was 1:1:0.1, and an appropriate amount of water (approximately 8 mL water per 10 g raw material) was added. Thereafter, the mixed material was pelletized to an LWA ball with diameter 6–10 mm and dried at room temperature (approximately 25 °C) for 3 days. The LWA samples were further dried at 110 °C in a blast roaster for 24 h. Samples were heated at a starting point of 25 °C, then further heated at a rate of 8 °C $min^{-1}$ in a muffle furnace, soaked respectively at 200, 600 and 800 °C for approximately 10 min and at test temperatures of 1100 °C for approximately 30 min. Thereafter samples were cooled naturally until they reached room temperature, before being stored in a desiccator for subsequent analysis of their physical properties.

#### 2.2.2. Methods

Chemical components of sewage sludge and river sediment were determined using AXIOS-PW 4400 XR spectrometer (X-ray fluorescence, XRF (WD-XRF), PANalytical, Amsterdam, Netherlands). Before being analyzed by XRF, sewage sludge and river sediment were dried at 105 °C until they reached invariable mass and then grinded in powders respectively.

Powder X-ray diffraction (XRD) spectra of LWA were recorded on a D/max-γb X-ray diffractometer at 50 mA and 40 kV, Cu Kα radiation (λ = 0.154 nm) (Rigaku, Japan). Data was collected 2$\theta$ in the range 10–90° at a scan rate of 0.02° $s^{-1}$.

Each LWA particle was divided into two halves, coated with gold and then glued onto a small flat disk for the observation of particle morphology by scanning electron microscopy (SEM). The analyses were conducted using a Quanta 200FEG scanning electron microscope (FEI, Hillsboro, OR, USA) at an accelerating voltage of 20 kV.

Water absorption, bulk density and grain density were used to determine the sintered pellet quality. Water absorption, bulk density and grain density were determined according to GB/T 17431.2-1998, China (lightweight aggregates and its test methods—part 2. test methods for lightweight aggregate), while solubility in hydrochloric acid was tested according to CJ/T 299-2008, China (artificial ceramsite filter material for water treatment).

The LWA compressive strength was analyzed using an automatic material testing machine (INSTRON 5569, INSTRON, Canton, MA, USA). Sintered LWA 5–8 mm in diameter was placed vertically on the platform and pressed at a crosshead speed of 0.5 mm $min^{-1}$ until crushed. The compressive strength (S) was determined from the average value of three replicate tests where $S = 2.8P_c/\pi x^2$, $x$ is the LWA sample sphere diameter and $P_c$ is the rupture load.

The aggregate sample toxicity was determined using a revised method derived from the toxicity characteristic leaching procedure (TCLP; US EPA Method 1311), a standard method to determine waste leaching toxicity and an updated hazardous waste extraction procedure provided by toxicity characteristic leaching procedure (US EPA Method 3050B). The heavy metals contents in acid digestion of sludge or LWA Leaching tests were conducted on a solution prepared at a liquid–solid ratio of 200 g $L^{-1}$, and stirred at 110 rpm for 24 h. The supernatant was analyzed using a Perkin-Elmer Optima 5300 DV Inductively Coupled Plasma Atomic Emission Spectrometer (ICP-AES, Waltham, MA, USA).

## 3. Results and discussion

### 3.1. Physical characteristics analyses

By calculating the content of each inorganic component of the raw material base as a function of the original