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Effects of a two-step heating process on the properties of lightweight aggregate prepared with sewage sludge and saline clay

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HIGHLIGHTS

- Sewage sludge and saline clay are utilized to produce LWA.
- Effects of a two-step heating process on the properties of LWA are investigated.
- Crushing strength, water absorption, density, LOI and shrinkage are studied.
- Preheating at 400 °C for 30 min and sintering at 1150 °C for 15 min is recommended.

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ABSTRACT

This paper investigates the effect of a two-stage heating process on the properties of lightweight aggregate (LWA) prepared with sewage sludge and saline clay. Initially, pyrolysis of sewage sludge and pelletized pellets was studied and it was found that the preheating temperature should be controlled between 400 and 600 °C in order to decompose the contaminant organic compounds and ensure that sufficient gases evolve during the sintering process for bloating of the internal structure of LWA. A total of 11 different preheating (400–600 °C) and sintering (1000–1150 °C) temperatures with varying holding times were studied and compared. The preheating test results demonstrated that the crushing strength of LWA is mainly influenced by temperature rather than holding time. As for the sintering process, an 1150 °C sintering temperature was a critical point to produce sufficient glassy phases and vitrified surface of LWA. Increasing the sintering temperature could enhance the crushing strength and density and resulted in a less permeable structure for water absorption. A shorter time (i.e. 5 min) of sintering is likely to provide better crushing strength; however, longer holding times could significantly reduce water absorption. The overall results suggested that the preheating temperature should be set at 400 °C for 30 min followed by sintering at 1150 °C for 15 min in order to produce lightweight aggregate with low bulk density (0.66 g/cm^3), water absorption (1.06%) and comparable high strength (11.1 MPa).

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1. Introduction

Lightweight aggregate (LWA) is receiving more popularity for use in different construction applications and concrete products, such as lightweight concrete, and lightweight bricks or blocks. Generally, LWA is artificially manufactured by a thermal process using natural clay, shale and slate or industrial by-products materials, such as fly ash, bottom ash, etc. [1–3]. It has been a common practice and has grown worldwide over the last few decades to utilize recycled wastes as replacement materials for natural clay in the production of LWA [4–7].

Wang et al. [4] produced LWA by utilizing dry sewage sludge as the principal material and coal ash as the addition. Sewage sludge was found to be effective for enhancing the pyrolysis-volatilization reaction due to its high content of organic material. The addition of coal ash increased the sintering temperature as well as decreasing the pore size, thereby enhancing the overall mechanical strength of LWA. Tuan et al. [5] investigated the feasibility of using wet sewage sludge and reservoir sediment to produce LWA.

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Incorporating a proper amount of reservoir sediment as an additive material increased the size expansion and crushing strength as well as offering lower bulk density and water absorption. The presence of waste glass demonstrated an improvement in sintering temperature and properties of LWA made from sewage sludge [6]. Mueller et al. [7] successfully manufactured LWA from recycled masonry rubble. LWA prepared with high content of ground brick powder demonstrated similar properties to those of natural material-based aggregate. Generally, LWA produced by various wastes or recycled materials is promising and possesses acceptable properties for different construction applications.

A few recent studies have reported the optimization of the production process of LWA. Gonzalez-Corrochano et al. [8] examined the effect of pre-firing and firing dwell times on the properties of artificial LWA. They concluded that expansion of LWA can be mainly controlled by the pre-firing dwell time. Both the pre-firing and firing times showed a significant influence on the formation of a vitrified external layer and interconnected pores. Lo et al. [9] proposed a new temperature profile to manufacture LWA by using high-carbon fly ash, in which the carbon served as a partial fuel substitute during the sintering process. Specifically, a holding stage at 830 °C for complete oxidation of the unburned carbon fly ash was proposed to provide internal space for further expansion and decrease the sintering period in the production of LWA. Zhang et al. [10] studied the effect of different cooling methods on the properties of LWA manufactured by high carbon ferrochrome slags and clay. It was found that a slow cooling process results in low porosity, finer pore size and a complete crystal structure. As a result, the strength gain was five times higher than for rapid cooling.

The management of sewage sludge derived from wastewater purification processes has been a public concern. Also, the saline clay contains a high salt level which is not suitable for plant cultivation and has low value for applications. Therefore, sewage sludge and saline clay were used as the main constitutes for the production of LWA in this study. This paper reports on a study to elucidate the effect of a two-stage heating process on the properties of LWA prepared with sewage sludge and saline clay. The effect of three different preheating temperatures and holding times were determined in terms of density, water absorption and crushing strength. Furthermore, other properties including loss of ignition and shrinkage were also considered in the sintering process to determine the optimal temperature and holding time, ensuring the LWA products prepared with sewage sludge and saline clay are of good quality and in line with the prevailing standards.

2. Experiment

2.1. Raw materials

Sewage sludge and saline clay used in this study were collected from a wastewater treatment facility and wayside close to the sea in Tianjin. Particle size distribution of sewage sludge and saline clay analyzed using a laser particle analyzer (see Fig. 1). The maximum sizes of sewage sludge and saline clay were 200 μm and 1.3 μm and their mean particle sizes were 38.0 μm and 0.9 μm, respectively. Smectite was used as an additive with particles with sizes of less than 0.075 μm. The morphology of sewage sludge and saline clay are illustrated in Fig. 2. Based on the XRD analysis, the main mineral constitutes of both sewage sludge and saline clay is quartz (see Fig. 3), and other minerals include anorthite, sanidine, albite, calcite and $Fe_4(PO_4)_3(OH)_3$ were also detected. The chemical compositions of sewage sludge, saline clay and smectite are given in Table 1. The main chemical compositions of sewage sludge are SiO_2, Al_2O_3 and Fe_2O_3, which represent 60% of the total weight. The relatively high SiO_2 in smectite and saline clay is expected to improve the strength of sintered LWA [4]. In addition, the presence of smectite in the mixture could help to enhance the viscosity for easy production of aggregates.

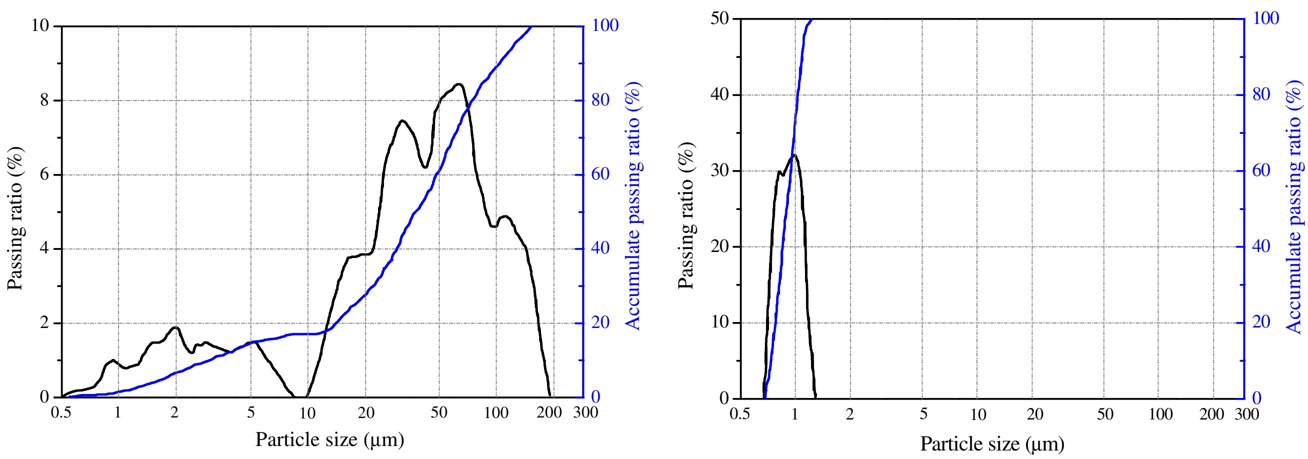

Fig. 1. Particle size distribution of (a) sewage sludge and (b) saline clay.

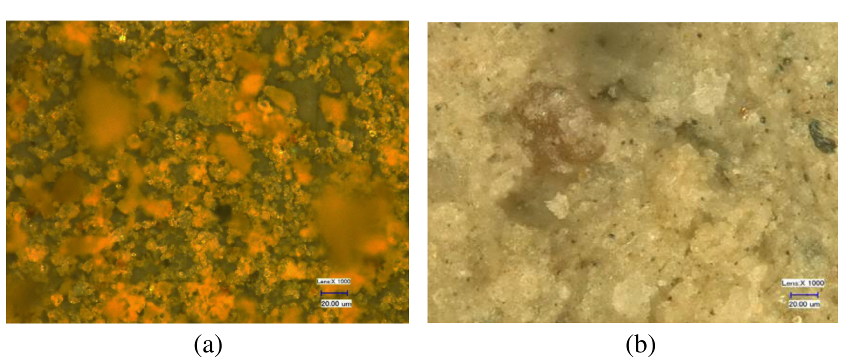

Fig. 2. Morphology of (a) sewage sludge and (b) saline clay.

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