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Production of Lightweight Aggregates from Sewage Sludge and Dredged Sediment

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ABSTRACT

In order to solve disposal problems of solid wastes, sewage sludge from wastewater treatment plants was mixed with dredged sediment to be recycled into lightweight aggregate through sintering process. The effect of sintering temperature, sintering time and mass ratio of sewage sludge to dredged sediment on characteristics of the aggregate were investigated to optimize the lightweight aggregate production process. Experimental results show that the optimal sintering temperature and time were 1150°C and 10 min respectively, and the optimal mass ratio of sewage sludge to dredged sediment was 7:3. It is concluded that sintering temperature and time, and sewage sludge/dredged sediment have a significant effect on the characteristics of lightweight aggregate.

INTRODUCTION

Sewage sludge is the final by-product of wastewater treatment plants. In china, due to the considerable increase in the amount of sewage sludge production, sewage sludge handling is becoming the most pressing issue in wastewater management (Ren et al. 2017, Dai et al. 2017, Zhang et al. 2016). Typical sewage sludge disposal methods, such as landfill, incineration and agricultural use are subject to certain restrictions because of their potential negative effects on the environment such as odour emissions, soil contamination and heavy metal pollution (Werle et al. 2010, Smith et al. 2009, Syed et al. 2017). The reuse of sewage sludge for lightweight aggregate production has been studied (Tuan et al. 2013, Jin et al. 2014, Lau et al. 2017) for several years. Lightweight aggregate has various applications due to its many advantages, namely, reduction of dead load, higher thermal and acoustic insulation and sound fire resistance properties. It has been a common practice over the last few decades to utilize waste such as sewage sludge as replacement materials for natural clay in the production of lightweight aggregate, because it not only avoids secondary pollution, but also adds value to the sewage sludge by transforming it into a useful material.

Dredged sediment is a silt-clay waste produced when deepening, broadening and maintaining of public waterways. Thus dredged sediments are rich in the mineral components (SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO) necessary for generating high quality lightweight aggregate. Previous studies have been focused on the production of lightweight aggregate with sewage sludge, several industrial sludges and different types of ashes (Lu et al. 2015, Laursen et al. 2006, Huang et al. 2013, Wang et al. 2009). However, few studies have combined sewage sludge and dredged sediment in lightweight aggregate production. The reuse of sewage sludge and dredged sediment for lightweight aggregate production has a great potential to resolve the problems in the management of both sewage sludge and dredged sediment. The objective of this study is to demonstrate the viability of recycling sewage sludge and dredged sediments for lightweight aggregate production.

MATERIALS AND METHODS

Characterisation of raw materials: The sewage sludge used was collected from the Wastewater Treatment Plant of Hanxi, Wuhan city and stored at 4°C before use. The main characteristics of sludge are listed in Table 1 and 2. Dredged sediment and clay used in this study were respectively obtained from Donghu Lake in Wuhan and Tiancheng brickfield in Huangshi, and their basic properties are given in Table 2.

Preparation and characterization of lightweight aggregates: The sewage sludge, dredged sediment and clay were dried at 110°C until constant weight was obtained. After sifting through the size of 75 μm, all the materials were evenly mixed. In this study, the weight percentage of clay to that of total dried solids (clay+sewage sludge+ dredged sediment) was 50%. The mixture was then pelletized to pellets of 5-10 mm diameter. The raw pellets were then sintered at temperatures of 950°C, 1000°C, 1050°C, 1100°C, 1150°C for different time and cooled under ambient air. The sintered

Table 1: Main characteristics of the sewage sludge.

Moisture (%)	Total solids (TS) (mg/L)	pH	Organic matter (%)
98.5	20200	7.07	79.5

Table 2: Chemical composition of dried sewage sludge, MSWI fly ash and clay (dry weight basis).

Oxide/%	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O
Sewage sludge	15.6	4.5	5.3	1.2	19.8	0.8	0.4
Dredged sediments	70.2	11.8	4.8	0.9	0.8	1.8	1.2
Clay	71.5	14.93	6.72	0.67	0.21	1.86	0.37

lightweight aggregates were then subjected to further examination. Apparent density (AD), compressive strength (CS), and 1h water absorption rate (WAT_{1h}) were all determined using an established procedure described by GB/T 17431.2-1998 (China EPA 1998a). The standard method for determining the leaching toxicity of solid wastes by horizontal vibration extraction procedure (GB5086.2-1997) (China EPA 1997) was used to evaluate the leaching of heavy metals from the sintered lightweight aggregate. The leaching properties of sintered lightweight aggregate were characterized by leaching rate and it is defined as a ratio of the leaching content of heavy metal in the sludge ceramsite to the total heavy metal content in the raw sludge.

RESULTS AND DISCUSSION

Effect of sintered temperature on the produced aggregate: Raw pellets were prepared with sewage sludge and dredged sediment at a mass ratio of 8:2 and the sintering time of 8 min. The effect of sintered temperature was investigated by physical characterization test of the produced lightweight aggregate. Fig. 1 shows the properties of lightweight aggregate produced at different sintering temperatures. It is readily seen that increasing the sintering temperature increased the AD and CS. This could be due to that lightweight aggregate sintered at higher temperature will have lower porosity which results in higher AD and CS. It could also be concluded that CS was positively related to the AD, lightweight aggregate with high AD had high CS.

As shown in Fig. 1, the WAT_{1h} of lightweight aggregate sintered at 1000°C and 1050°C were 33.3% and 27.5%, above the limit prescribed by GB/T17431.1-1998 (China EPA 1998b). However, WAT_{1h} was reduced sharply as the sintering temperature increased and 11.8% was recorded at 1150°C. The water adsorption rate mainly depends on the open pores of lightweight aggregate and pores are mainly formed by a glassy phase wrapping gas. High temperature will form glassy phase and seal smaller pores, decreasing water adsorption. This indicated that the appropriate amount of glassy phase is formed at the temperature of 1150°C. As demonstrated in Fig. 1, when the temperature increased from 1150°C to 1200°C, the WAT_{1h} of lightweight aggregate increased to 13.7%.

Effect of sewage sludge to dredged sediment ratio on the produced aggregate: The above results indicate that 1150°C is the appropriate temperature. The various sewage sludge/dredged sediment ratios of the raw materials were used to produce lightweight aggregate samples and the samples at each ratio in the experiment were sintered at 1150°C for 8 min. Fig. 2 shows that AD of lightweight aggregate increased from 320 to 680 kg/m^3 when the sewage sludge/dredged sediment ratio was increased from 10:0 to 7:3, and then a slight increase was observed at 6:4. A similar trend was observed for CS. As shown in Fig. 2, the CS of lightweight aggregate gradually increased in the ratio range of 10:0 to 8:2 and a slow increase was observed when the ratio decreased to 6:4. On the other hand, an opposite trend was observed for WAT_{1h}. WAT_{1h} of lightweight aggregate decreased as the sewage sludge/dredged sediment ratio decreased to 7:3, while it increased to 10.5% as the sewage sludge/dredged sediment ratio decreased to 6:4. The results show that the WAT_{1h} increases as the proportion of sewage sludge in the raw pellets increases from 70% to 100%. These results indicate that with higher sewage sludge proportion, the lightweight aggregate structure is loose and compressive strength is low, while the 1h water absorption rate is high. It was concluded that the optimal mass ratio of sewage sludge to dredged sediment is 7:3.

Effect of sintering time on the produced aggregate: In order to evaluate effects of the sintering time on the produced aggregate, the sintering time of 5 min, 8 min, 10 min and 12 min was studied. The above results indicate that 1150°C is the appropriate temperature and the optimal mass ratio of sewage sludge to dredged sediment is 7:3. Thus, all aggregate samples were produced under the optimum condition. Fig. 3 shows the variation of CS, AD and WAT_{1h} with sintering time. Aggregates sintered with shorter time, ex-

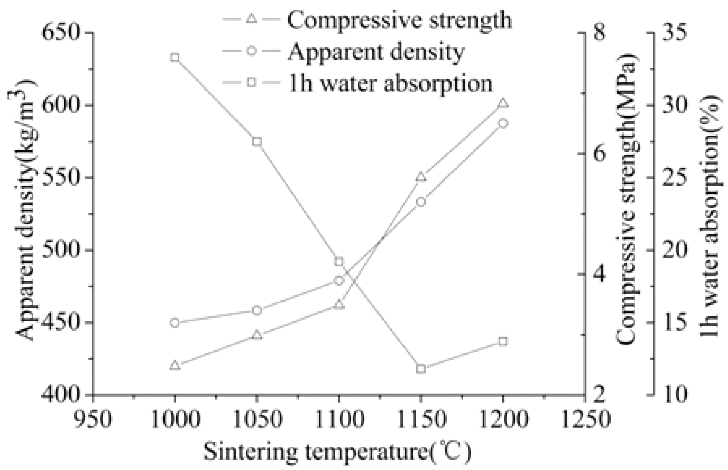

Fig. 1: Effect of sintered temperature on the produced aggregate.

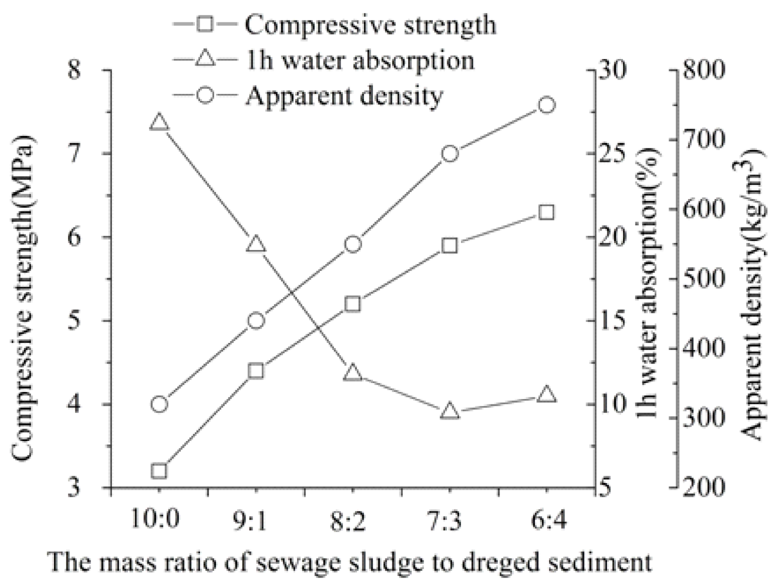

Fig. 2: Effect of sludge to dredged sediment ratio on the produced aggregate.

hibited low strength, as illustrated in Fig. 3. This may due to the loosely bounded matrix of aggregate which were weak to withstand external forces. Similarly, AD of aggregates increased continuously with the sintering time, as illustrated in Fig. 3. On the other hand, WAT_{1h} decreased with the increasing sintering time. As shown in Fig. 3, the WAT_{1h} sharply decreased in the time range of 5-8 min, but a slow decrease was observed when the sintering time increased to 10 min, and then it increased to 11.8% at 12 min sintering time. It is inferred that a further increase of sintering time (up to 10 min) may not provide a significant enhancement of aggregate properties.

CONCLUSIONS

The potential utilization of two types of wastes, sewage sludge and dredged sediment, as raw materials to produce lightweight aggregates were evaluated. It can be concluded from the results and discussion above that sintering temperature, mass ratio of sewage sludge to dredged sediment and sintering time all have a significant influence on the lightweight aggregate. It can be seen from all the figures that the variation of CS, AD and WAT_{1h} of lightweight aggregate follow a similar trend. Thus, the optimal sintering temperature (1150°C), the optimal mass ratio of sewage sludge to dredged sediment and the optimal sintering time

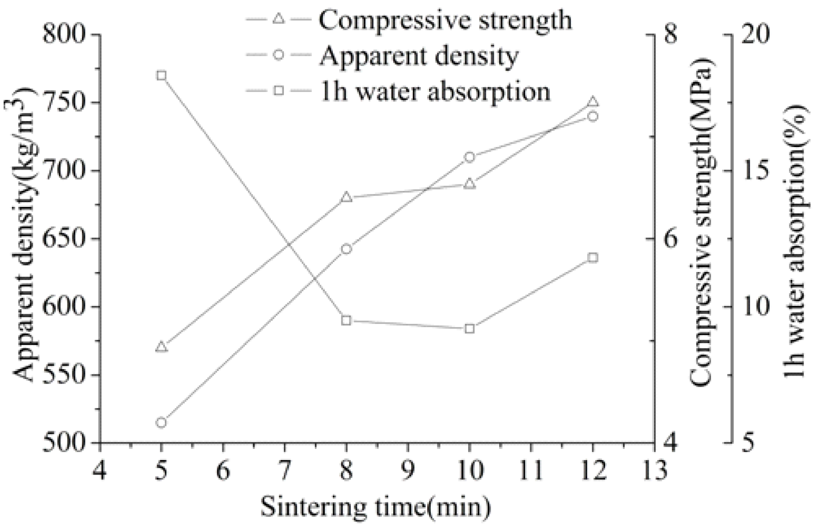

Fig. 3: Effect of sintering time on the produced aggregate.

(10 min), were similarly determined. It also indicates that lightweight aggregate made with sewage sludge and dredged sediment, as an additive is comparatively sustainable sludge and sediment disposal application.

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