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Short communication

Effects of heat treatment on the physical properties of lightweight aggregate from water reservoir sediment

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Abstract

Lightweight aggregates (LWAs) were produced from water reservoir sediment with added calcium oxide by employing four heat treatments, respectively, at temperatures in the range of 1170–1230 °C. The results show that LWAs produced at temperatures above 1200 °C meet European Union regulation EN-13055-1, which states that the unit weight of LWAs should be lower than 2000 kg/m^3. The bulk density was easily lowered by extending the soaking time and increasing the heating rate. The ratio of strength to unit weight of the LWA produced at 1230 °C with a short soaking time and a fast heating rate was near that of a commercial product. The level of water adsorption was below 4%, which increased initially and then decreased due to pore connections and pore sealing. The formation of a glassy phase made the LWAs treated at higher temperature rough and sealed small pores (<0.1 mm) connected to the walls of large pores (>0.2 mm). The mineral phases of the LWAs were quartz, anorthite, and hematite.
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1. Introduction

Lightweight aggregates (LWAs) are widely applied in the production of lightweight concrete for high-rise buildings due to their low weight. The porous structure of LWAs gives them properties of acoustic and thermal insulation. The formation of a porous structure was inferred by Riley [1], who suggested that bloating behavior has two causes. One is that raw materials have a chemical composition which can form a glassy phase that wraps gas, and the other is that gas is generated as the glassy phase forms. In Riley's study, a diagram composed of SiO_2, Al_2O_3, and flux oxide includes a bloating area where a bloating behavior occurs. Many recycled wastes located in the bloating area are manufactured into LWAs, such as mined residue [2–6], ash [7–11], and sludge [12–16]. Water reservoir sediment also locates in the area.

Water reservoir sediment greatly shortens the usage life of reservoirs. In order to extend the reservoir life and recover water storehouses, dredging operations are performed after the rainy season. The swept sediment is usually disposed of downriver, which can damage the ecology due to silt suspension. According to a government report, an average amount of 14 million metric tonnes of sediment precipitates annually in Taiwan; the total amount of swept sediment in 2009 was 4.33 million metric tons. Recently, Chen et al. [7] and Wei et al. [17] have reported that it is feasible to use water reservoir sediment, which can be mixed with other recycled wastes, to produce LWAs. Tang et al. [18] manufactured LWAs from reservoir sediment for lightweight concrete. Their results showed that the performance of LWAs from reservoir sediment was better than that of commercial LWA. In the process of manufacturing LWAs, heat treatment greatly affects their physical properties because temperature controls bloating behavior, which determines the formation of the porous structure. de'Gennaro et al. [4] used an optical lens to observe the bloating behavior of LWAs manufactured from Neapolitan Yellow Tuff during the heating process. The maximum bloating temperature was determined for LWAs when the bottom of the LWAs was in flat contact with the refractory brick. Pore size was also found to increase gradually with distance away from the refractory brick. Chen et al. [7] mixed water reservoir sediment and various ashes to produce LWAs preheated at

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500 °C; the LWAs were fired at 1150 °C and 1175 °C with soaking times of 10 min and 15 min, respectively. The longer soaking time increased the particle density of LWAs and reduced the water adsorption.

However, few studies have directly examined how heat treatments including heating rate, duration time, and temperature affect the physical properties of LWAs. In the present study, various heat treatments were employed to produce LWAs from water reservoir sediment with added calcium oxide. In our previous study [19], calcium oxide was found to reduce the water adsorption of LWAs. Since water adsorption affects the setting time of concrete, it is better for using LWAs with low water adsorption in the production of lightweight concrete. After being calcined at various temperatures, the physical properties, macrostructure, and microstructure of LWAs were investigated.

2. Materials and methods

The water reservoir sediment was obtained from Shihmen Reservoir, which is the largest reservoir in north Taiwan. The sediment with a median particle size (d_{50}) of 8.49 μm had a water content of 28% and an ignition loss of 5.57%. The sediment was dried at 120 °C and milled to pass through a No. 100 mesh for further measuring. The chemical composition of the sediment was determined using an X-ray fluorescence spectrometer (XRF, Rigaku). Mineral phases were analyzed using X-ray diffraction (XRD, Siemens D5000).

CaO powders (Shimakyo's Pure Chemicals) were milled to pass through a No. 100 mesh. 5% CaO by weight was directly mixed with the water reservoir sediment by a small cement mixer without drying. The mixture was extruded by a vacuum extrusion machine. The extruded bar was cut into small lumps to be pelletized into 10–20 mm diameter spheres. The spheres were left to stand in the atmosphere at room temperature for one day and then heated in a laboratory-scale furnace. Heat treatment with a soaking time of 30 min and a heating rate of 5 °C/min was employed (denoted as 3005, where first two numbers represent the soaking time and the last two numbers represented the heating rate. Likewise, other treatments were denoted as 3015, 1505, and 1515, respectively. The heating temperature was controlled from 1170 °C to 1230 °C in increments of 15 °C.

The physical properties of the heated LWAs were characterized. The bulk density and water adsorption were measured using the Archimedes method after the LWAs were placed in boiling water for 24 hr. The bulk density and water adsorption were calculated using Eqs. (1) and (2) [20]. The compressive strength was measured using a compression testing system (MTS) with a cross-head speed of 0.1 mm/s. The compressive strength of the heated LWAs was calculated using Eq. (3) [21,22].

$$\text{Bulk density} = \frac{W_D}{W_S - W_I} \tag{1}$$

$$\text{Water adsorption } (\%) = \frac{100(W_S - W_D)}{W_D} \tag{2}$$

$$\text{Compressive strength} = \frac{2.8P_c}{\pi X^2} \tag{3}$$

where W_D is the dry weight of the heated LWAs, W_S is the 24 h saturated surface-dry weight, and W_I is the immersed weight in water. P_c is the fracture load and X is the diameter of the LWAs.

Each recorded testing value was the mean of results obtained from eight samples. Mineral phases of the aggregates were analyzed using XRD after they were crushed into powders through a No. 100 mesh. An optical microscope was employed to observe the appearance and cross-section of samples. Finally, the microstructure of the 3005 and 3015 series of samples was investigated using a scanning electron microscope (SEM).

3. Results and discussion

Table 1 shows the chemical composition of the water reservoir sediment detected by XRF. The sediment was mainly SiO_2 (61.4%), followed by Al_2O_3 (22.5%) and Fe_2O_3 (8.6%). Mineral phases of the sediment with 5 wt% CaO and the raw sediment were analyzed by XRD. Fig. 1 shows the XRD pattern of raw sediment and sediment with added CaO. The mineral phases for the raw sediment and the sediment with added CaO were the same. The mineral phases were quartz (PDF#: 83-2539), albite (PDF#: 41-1480), clinochlore (PDF#: 46-1323), and muscovite (PDF#: 46-1311).

Fig. 2a shows the bulk density of LWAs subjected to various heat treatments. The bulk density decreased with temperature. The 3015 series of samples had the lowest bulk density at various heating temperatures, and the bulk density ranged from 2.02 g/cm^3 to 1.12 g/cm^3. The bulk density of the 1505 and 1515 series of samples were lower than 2 g/cm^3 above 1200 °C. Although the bulk density of the 1505 series of samples was higher than those of other samples below 1215 °C, it was lower than that of the 1515 series of samples above 1215 °C. To lower the bulk density at high temperature, a slow heating rate should be applied for a short duration time. The bulk densities of the 3005 and 3015 series of samples produced at a given soaking time were similar at temperatures above 1200 °C, and different from those of the 1505 and 1515 series of samples. This indicates that a longer soaking time and a faster heating rate easily reduced the bulk density, which decreased at a constant

Table 1
Chemical compositions of Shihmen Reservoir sediment.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Composition (wt%)	61.4	22.5	8.6	0.7	2.0	1.3	3.4

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