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The influence of hydration and swelling properties of gypsum on the preparation of lightweight brick using water supply reservoir sediment

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HIGHLIGHTS

- The material properties of reservoir sediment were analyzed.
- A procedure to produce lightweight brick made of reservoir sediment was proposed.
- Gypsum content shows a dominating effect on density and compressive strength.
- Parameters analysis and material performances of the sintering brick are considered.
- The influence of adding gypsum on light weighting is feasible for application.

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ABSTRACT

The sediment of the Taiwan Shihmen Reservoir was used as the main material for sintering specimen. This study developed sintering bricks by adding various amounts of gypsum (10–30%), as well as changing the sintering temperature, sintering time, and water content. The Taguchi Orthogonal Array was used for experimental design and the density, shrinkage variation, and the mechanical performance were analyzed, in order to apply lightweight bricks to partition walls. The results showed that the gypsum hydration and swelling properties reduced the dry shrinkage and overall shrinkage of sintered material. The sintered brick had lower density than the control groups (the sintered materials without gypsum content) and red bricks on the market. In application, an appropriate material proportion (20% gypsum) was sintered into bricks, and the brick pier was used for compression test. The test results showed that the sintered bricks could be applied to lightweight partition walls. With a view to reducing the utilization of natural resources, using waste, and reducing cost, it is feasible to sinter reservoir sediment into lightweight brick.

1. Introduction

The green building material labeling system of Taiwan emphasizes the recycling of green building materials, in an attempt to promote the reuse of recycled materials and reduce waste. Among the approved cases of green building materials from 2005 to 2012, there were 34 recycling green building material labels (8%), 57 high performance green building material labels (13.4%), and 329 healthful and ecological green building material labels (78.6%). It is obvious that recycled building materials should be highly valued. In addition, if the building materials have good performance and can overcome the defects in the performance of traditional building materials, thus improving the superiority of products, the requirement for high performance green building materials can be satisfied. According to the definition of good materials by Spillman [1], the technology and development of building materials should include: (1) the reutilization of waste and the application of industry residual products; (2) the environmental load of building material production and product performance evaluation. This concept meets the basic characteristics of Taiwan's green building materials: the content of natural resources as raw material for construction should be reduced as much possible, and the design of products should aim at improving application requirement and sustainable design [2]. Moreover, the products should be recyclable and bring less environmental pollution and waste [3]. The present construction industry's concepts and technology in response to environmental and ecological variation are in urgent need.

The severity of the problem of reservoir sediment in Taiwan is similar to that in California and Japan. Since the Taiwan Shihmen Reservoir began to store water in May 1963, typhoons, rainstorms,

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and other natural and man-made disasters have reduced the 290 mm^3 water storage volume by 40% [4], severely impacting the reservoir's storage function and normal operation. Typhoon Aere and Typhoon Mindulle in 2004 resulted in 27.8 mm^3 of sediment deposition according to a survey of the Taiwan Water Resources Office, Ministry of Economic Affairs. The goal is to remove 250 km^3 sediment per year, so as to reduce the deposition in the reservoir. However, it is difficult to dispose of such a large amount of sediment. Reusing reservoir sediment can provide an alternative solution, and further utilize Taiwan's resources.

Lightweight aggregate sintering technology has improved gradually, and related studies have developed lightweight aggregate on sediment, fly ash, combustion ash and fresh water sludge [5–8]. The materials have been tested for performance and have also been widely applied. Tang [9] sintered TFT–LCD glass powder and reservoir sediment to obtain a lightweight aggregate meeting the performance requirements. Bhatty and Redit [10] indicated that their specimen powder provided better workability and specimen compactness, because the pore size distribution in the specimen was consistent, and the foaming was uniform. The glassy layer generated from the formed specimen caused high viscosity, so that the specimen foaming was concentrated, and the specimen was lightened. Wei and Lin [5] studied reservoir sediment, of which the main constituent was SiO_2 (64.55%), with an Al_2O_3 content of 16.06%, and a fluxing agent of about 19.39% (fluxing agent: $Fe_2O_3 + K_2O + Na_2O + CaO$), and found that the constituents could be sintered into lightweight aggregate. Chiang [11] sintered a mixture of clay and reservoir sediment, and changed the sintering temperature. The findings showed that the heavy metal leaching from the sintered body was much lower than Taiwan's standard. The compressive strength was at its maximum when the sintering temperature was 1100 °C. Rahman [12] added rice husk ash to clay and sand to make light bricks. The results of this study showed that the addition of rice husk ash had no effect on the quality of bricks, and the compressive strength of the bricks increased with the addition of more rice husk ash, meeting the test criteria for bricks. Baspinar et al. [13] indicated that in the sintering process of waste containing $CaSO_4$ in large particle sizes and clay in small particle sizes, the fine particles could fill up the gaps, which was favorable for stacking sintered particles. In other words, part of the constituents of the product of gypsum board powder was decomposed at 950–1050 °C. The gypsum content caused swelling in the material research and development [14]. Diatomaceous earth, lime, and gypsum have been mixed to develop lightweight bricks. The findings showed that different gypsum contents changed the strength and density of bricks [15].

In addition, a series of investigations have been carried out using gypsum in preparing the building material of non-fired bricks [16–18]. The physical and mechanical properties were investigated using borogypsum and semi-hydrated borogypsum as cement additives in prepared cements [19]. In recent years, Emrullahoglu Abi [20] has presented a study of the effects of using the borogypsum ($CaSO_4{\cdot}2H_2O$) of boric acid production waste on brick properties. The brick clay and borogypsum (10 wt%) mixtures obtained a better compressive strength and decreased the bulk density of bricks. Vasconcelos et al. [21] have investigated the design process of the block in order to obtain an innovative solution for partition walls from flue-gas desulfurization gypsum (FGD gypsum), with the aim of reducing construction waste and energy consumption during building' life-cycle. They concluded that the material and construction technology could provide good mechanical and thermal properties, and fulfill the stability and other requirements for partition walls. The composition of FGD gypsum is similar to natural gypsum and it is easy to obtain high purity. A hydration – re-crystallization process for preparing non-fired bricks involves hot-drying at 180 °C to dehydrate gypsum into semi-hydrated gypsum ($CaSO_4{\cdot}1/2\ H_2O$) [22]. The industrial application of this method could help to significantly reduce environmental waste and enhance mechanical strength. The bi-hydrated gypsum ($CaSO_4{\cdot}2H_2O$) could be modified to semi-hydrated gypsum ($CaSO_4{\cdot}1/2H_2O$) through calcinations process. The water-immersed semi-hydrated gypsum will re-crystallize and turn into new gypsum ($CaSO_4{\cdot}2H_2O$) crystals with irregular and porous microstructures. Muñoz Velasco et al. [23] have provided a review of research concerning the addition of different types of wastes into fired clay bricks. Four groups, organic, sludge, ashes, and inorganic additives in brick production were discussed along with procedures for making bricks and testing methods. In order to summarize the effects of the addition of certain wastes, they analyzed the material properties of water absorption, compressive strength, and bulk density as well as application characterization. In this research, sintered bricks were evaluated to determine their usefulness with β semi-hydrated gypsum added to reservoir sediment to improve its lightweight property and compare the sintered brick with those bricks with inorganic additives [23].

In view of above, this study applied the hydration and swelling properties of gypsum to the sintering of reservoir sediment, to explore the performance of lightweight bricks in building partition walls. The Taguchi method was used to design the experimental parameters, so as to discuss the volumetric shrinkage, density, water absorption, bending strength, and compressive strength under different parameters, to analyze the performance differences under different parameters.

2. Experimental materials and method

This study combined the sediment from Taiwan Shihmen Reservoir with β-gypsum ($CaSO_4{\cdot}1/2H_2O$), and changed the sintering temperature, sintering time, and water content, to discuss the practicality of its application to partition walls according to its basic and mechanical properties.

2.1. Specimen preparation and sintering procedure

The reservoir sediment was collected from the settling tank of Shihmen Reservoir. The sediment was dried under the sun and thoroughly ground, and then dried at 100 °C for 24 h in a dry-oven before making the specimen to minimize the water content in the sediment. Due to the swelling effect of gypsum as it absorbs water and hardens [24,25], the β semi-hydrated gypsum was used in this study. Since the standard mix water content in β semi-hydrated gypsum was about 70%, the solidifying time was 25–35 min, and the water ratio for sediment molding was about 20%. Thus, the water content in the sintering process in this study is 35–45%. The test specimens were prepared by mixing the dried reservoir sediment and β semi-hydrated gypsum of 10%, 20%, and 30% (% by weight). Different proportions of water (35%, 40%, and 45%) were added slowly to the dry powder and mixed it by a mechanical mixer, then poured completely in the mold and pressed with a pressure of 5 MPa. A hydraulic press was used to make bricks with 220 mm (L) × 110 mm (W) × 55 mm (H) in size. The shaped bricks were removed from the molds after approximately 24 h and were dried in an electrical furnace maintained at 100 °C for 48 h before sintering. In terms of sintering temperature and time, the sintering temperature was increased from room temperature to 105 °C for 30 min to evaporate moisture, and then gradually increased to the sintering temperature at 5 °C/min. The sintering temperature variation range was 900–1100 °C, the sintering time was 30 min, 1 h, and 2 h, respectively.

2.2. Material characteristics

Shihmen Reservoir sediment is classified as fine sands (ML) and silty clay (CL) based on the Unified Soil Classification System. According to the X-ray diffraction (XRD) analysis of the reservoir sediment through #200 sieve (Fig. 1), the sediment contains five crystalline phases: Quartz, Ferrosilite, Illite, Clinochlore and Orthoclase. According to the aforementioned crystalline phases, the reservoir sediment consists of SiO_2, Al_2O_3 and other fluxes (CaO, MgO, Fe_2O_3, K_2O, Na_2O). This study uses Inductively Coupled Plasma Atomic Emission Spectrometry (ICP–AES) to analyze the chemical composition of reservoir sediment and gypsum. The sediment contains 58.15% SiO_2, 19.69% Al_2O_3, and 7.47% Fe_2O_3. Shihmen Reservoir sediment composition and the Toxicity Characteristic Leaching Procedure (TCLP) are shown in Table 1, which shows the composition ratio of sediment in different studies [5,9,11,26]. As seen, the composition of Shihmen Reservoir sediment is