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Preparation of non-sintered lightweight aggregates from dredged sediments and modification of their properties

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HIGHLIGHTS

- Dredged sediments are utilized to produce non-sintered lightweight aggregates.
- WLAs and WSLAs are manufactured by waterproofing and wrap-shell process.
- Superior performance of WSLAs is due to pozzolanic reaction of the shell layer.
- Silicon polymer membrane ensures WLAs equip with a hydrophobic surface.
- Hard concrete shell is important for non-sintered LWAs applied in harsh environment.

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ABSTRACT

A novel preparation technique of non-sintered lightweight aggregates (LWAs) from dredged sediments was conducted in this study. In order to deal with the problem of hydration and low strength of the ceramsites without calcination, waterproofing lightweight aggregates (WLAs) and wrap-shell lightweight aggregates (WSLAs) are manufactured through the process of waterproofing and wrap-shell, respectively, and untreated lightweight aggregates (ULAs) were utilized as core layer. The performance characteristics, such as basic physical properties, mechanical strengths, water resistance, harsh environment resistance, and microstructure, of ULAs, WLAs and WSLAs were investigated. Results show that ULAs have a uniform particle size distribution, but their compressive strength is rather low (0.27 MPa), and the value of water absorption was as high as 24.18%. WSLAs were equipped with a hard and stable concrete shell, which raised their compressive strength to 2.46 MPa, and the salt, frost and shearing resistance were improved. These results reveal that, if dredged sediment would be used as raw material for producing non-sintered LWAs in concrete pouring, a stable shell layer was extremely essential to avoid their obtained specimen from crushing or being hydrated.

1. Introduction

Dredging operations are necessary for irrigation and water transport to keep the normal maritime and river activities. The global sediments produced by this process were as many as hundred millions of tons annually [1]. Generally, dredged sediment is a type of very soft soils with notably low mechanical strength and extremely high moisture content. Apart from that, the sediments may be contaminated with heavy metals and organic pollutants [2,3]. In many countries, dredged sediment are frequently physically treated and dewatered before disposal, and the typical practice of disposal are landfill, application to farmland and forestry and sea dumping. The most common methods of dewatering is putting the dredged sediment in an area to dewatered naturally, but this process would take long time and caused secondary pollution [4]. Therefore, regeneration and beneficial reuse of dredged sediment have mainly been explored in long time. The search for cost-effective and eco-friendly disposal options has become most pressing matter because of tighter environmental regulations, declining public acceptance of other solutions in many countries [5].

Traditional lightweight aggregates (LWAs) were made from mineral resources, such as clay and shale, and fly ash in common. An increasing number of large-scale construction projects, such as Stolma bridge and Nordhordland bridge in Norway, Charter Oak

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bridge in Connecticut, Woodrow Wilson bridge in Washington, the World Trade Center in New York, and Zhuhai International Conference Center in China are favored by the use of LWAs as building materials. However, continually producing and consuming LWAs seems not sustainable, and the mainly reasons are discussed as followed. On one hand, due to accelerating urbanization process, demand for clay and shale is expected to be continuously rising, and these mineral resources are being consumed year by year [6,7]. Thus, taking into account resource conservation and environmental protection, many countries, such as China, have restricted, or even forbidden, to make use of natural mineral to produce any construction materials [8–10]. One the other hand, the number of traditional thermal power plants are being reduced gradually, and hydroelectric power and other new electricity generation model has begun to replace the fossil energy. Thus, the quantity supplied of fly ash, which is one of the coal combustion products, and also is essential raw material of LWAs, couldn't remain their original advantage anymore. Fortunately, owing to the flexibility of the aggregates composition, different types of industrial waste could successfully be used as raw materials for preparing aggregates by previous researchers [11–17]. In consideration of the quantity and property of dredged sediments, it would play a competent role in producing newfangled construction material.

In previously reports, sintering is a common used method in preparing dredged sediment aggregates [6]. Mun [18] treated sewage sludge discharged from sewage treatment plants and sintered LWAs from sludge, then utilized as a part of lightweight concrete. Yang [19] reported their study in producing LWAs made of fine sediments from the Shihmen Reservoir in the northern Taiwan. And these sintered LWAs possessed a relative density ranging from 1.01 g/cm^3 to 1.38 g/cm^3, which is significantly lower than commercial LWAs. Tuan [20] also prepared LWAs with wet sewage sludge as the principle material and used waste glass as the additive. The lightweight concretes made of these LWAs could be considered as good quality concretes. Though the process of calcination could improve the aggregates physical property, large amounts of fossil resources would be consumed. Moreover great deal of mist or haze might be generated due to burning of fossil fuels [21–23].

Even if the non-sintering process avoids consumption of fossil fuels, there are also some drawbacks were observed in previous studies. Miqueleiz [24] utilized alumina filler wastes as raw material for unfired brick production, and find their compressive strength was lower than 28 MPa, and the maximum rate of water absorption was 24%, and some fractures also are observed in freezing and thawing test. Chen [25] reported the utilization of the sludge for manufacturing unfired bricks, the compressive strength was 40 MPa and the mass loss rate <5% and strength loss <15% in freezing-thawing tests. It can be seen from these previous reports that the building materials, such as bricks, produced by non-sintering technique couldn't ensure high strength or waterproofing compared with the brick after calcination.

In this study, non-sintered LWAs were prepared by utilizing dredged sediment as raw material. In order to avoid the intrinsic drawbacks of the aggregates without calcination, waterproofing or wrap-shell treatments of LWAs is firstly proposed in this paper. The performance characteristics of all three samples were investigated by measuring and analyzing their mechanical strengths, water resistance, and harsh environment resistance. The practice of taking the dredged sediment as raw material, not only solved the problem of disposal, but also protects the mineral resource from overexploitation. Furthermore, the shaping process of aggregates without calcination would achieve the goal of lessening energy consumption and preventing harmful gas emission. This novel non-sintered aggregate could comply with the requirements of building materials of current construction industry.

2. Materials and methodology

2.1. Properties of materials used in aggregates production

The dredged sediments used in this study were collected from Dianchi Lake in China, and their basic properties are shown in Table 1. Portland cement 42.5R was supplied from Tianjin KunBoYi Co., Ltd, China. Fly ash was obtained from Tianjin Huadian Nanjiang thermal power plant. Other chemicals used in the experiment are the following: calcium oxide (HuaShengTianHe Chemical Co., Ltd, China), phosphogypsum (JinHuiTaiYa Chemical reagent Co., Ltd, China), water glass (LeTai Chemical Co., Ltd, China), white glue (XinShuangYing Building Materials Co., Ltd, China), and organosilicon waterproofing agent (KunNai Building Materials Co., Ltd, China). Chemical composition of dredged sediments, Portland cement, fly ash, calcium oxide and phosphogypsum are exhibited in Table 2. Laser diffraction particle size analyzer 13320 was used to determine the grading of the materials, and the particle size distribution of dredged sediments is so fine that the peak of their size is concentrated on 7.461 μm.

2.2. Preparation of non-sintered LWAs

A disc pelletizer was utilized for manufacturing the non-sintered LWAs in our study, and the size of the disc is 28 cm in diameter and 27 cm in depth. While the pelletizer operated, the disc worked in a condition of the angle is 45° and the speed is 45 r/min based on previous report [26]. The flowchart for preparing non-sintered aggregates was shown in Fig. 1. According to our previous study, which have been patented [27], the optimum compositions of raw materials was recommended as the following: dredged sediment, 80%; cement, 3%; lime, 3%; phosphogypsum, 3%; fly ash, 5% and water glass, 6%. After the dry raw materials mixed plenty, the powder mixture was poured into the disc pelletizer. Then water glass aqueous solution, the weight ratio of solution to the powder was 22–25 wt%, was sprayed onto the powder mixtures for the purpose of forming spherical pellets. After the disc pelletizer rolling for 0.5 h, the obtained pellets were natural cured 7 days under ambient temperature. In the previous 4 days, 20 g water was sprayed onto a kilogram of aggregates at intervals of 12 h, and in the last 3 days, interval time of spraying water was adjusted to 24 h. Finally, untreated aggregates were labeled as ULAs.

Waterproofing lightweight aggregates (WLAs) were prepared by utilizing ULAs as carrier, and sprayed organosilicon solution (10 wt%) as waterproofing agent on their surface with the weight ratio of 1:5. Similarly, wrap-shell lightweight aggregates (WSLAs) were manufactured by a coating process, which used ULAs as core layer, mixed with white glue emulsion (4 wt%) and raw materials powders in the disc, and their optimum compositions of shell layer have been recommended as the following: ULAs, 70.0%; cement, 21.6%; lime, 1.5%; fly ash, 3.9% and white glue, 3.0%. The disc continued rotating until the powder mixture covered ULAs completely, and this process would take 15 min approximately. The photographs of raw materials, equipment and LWAs productions (ULAs, WLAs and WSLAs) were shown in Fig. 2.

2.3. Basic physical properties characterization

The basic physical properties of three groups of aggregates were examined in accordance with the Chinese National Standard GB/T 17431.2