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Performance assessment of core-shell structured lightweight aggregate produced by cold bonding pelletization process

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HIGHLIGHTS

- Core-shell lightweight aggregates were produced by cold bonding pelletization process.
- Influence of production parameters on the aggregate properties was investigated.
- Effects of incorporation of expanded perlite powder into the shell matrix were assessed.
- Lightweight aggregate with particle density ranges from 0.88 to 1.14 g/cm^3 were obtained.
- Performance of fly ash and expanded perlite powder as mineral admixtures was studied.

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ABSTRACT

The density of cold-bonded lightweight aggregates is significantly higher than that of sintered lightweight aggregates. Since the sintering technique consumes an enormous amount of energy and emits a huge amount of pollutants, the implementation of a cold-bonded method, in manufacturing low-density lightweight aggregates, is very important from an economic and environmental perspective. In this study, a cold bonding granulation technique was employed to produce low-density lightweight aggregate by the encapsulation of expanded perlite particles in shell structures. A variety of tests were conducted to evaluate the physical and mechanical properties of the aggregate produced. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to study the microstructure and the phase composition of the aggregate. Furthermore, X-ray micro-computed tomography (CT) was performed to investigate the pore system of the aggregate specimens. The obtained results showed that by adopting the angle and speed of pelletizer disc, a core-shell structured lightweight aggregates with particle density of 0.88–1.14 g/cm^3 and bulk crushing strength of 2.04–2.66 MPa can be produced.

1. Introduction

Recently, lightweight aggregates (LWAs) have attracted great interest and large industrial demand in a wide range of construction products. They have lower density and thermal conductivity than conventional aggregates, thus offering important economic and environmental benefits [1,2]. LWAs can be natural or artificial. The usage of natural aggregates has become a contentious issue due to their over use in addition to the lack of natural sources in most areas [3,4]. Consequently, the utilization of artificial LWAs in various construction products has been growing dramatically. Artificial LWAs can be produced via sintering or cold bonding technique. The sintering method has two main disadvantages: large energy consumption and the emission of huge amounts of pollutants [5]. On the contrary, the cold bonding method has the potential to satisfying from both economic and environmental perspectives, due to its potentially lower energy consumption if the requirements for density and strength can be improved.

Many studies in recent years have concentrated on the manufacturing of cold-bonded LWAs. Such research efforts have focused on recycling different by-products or waste materials as LWAs, regardless of the density of the aggregates produced. Gesoğlu et al. [6] have produced a cold-bonded aggregate with a specific gravity of 2.14 g/cm^3 by using ground granulated blast furnace slag (GGBFS) in the manufacturing process. Kumar et al. [7] have utilized fly ash and cement at different cement/fly ash ratios, with the aggregate having specific gravity ranges between 1.72 and 1.97 g/cm^3, depending on the cement content. Chi et al. [8] have reported that fly ash and cement can also be used to produce

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LWAs, with an oven dry specific gravity between 1.23 and 1.44 g/cm^3, and a corresponding particle strength of 6.04–8.57 MPa. Thomas and Harilal [9] have developed a cold-bonded quarry dust coarse aggregate with a specific gravity of 1.9–2.5 g/cm^3, which is similar to that of normal weight aggregate. Colangelo and Cioffi [10] have employed cement kiln dust, GGBFS and marble sludge in their manufacturing process. The aggregate fabricated had a dry density of 1.7–1.98 g/cm^3.

One of the main disadvantages of cold-bonded LWAs is its high density compared to most of sintered LWAs available in the market, such as expanded clay and expanded glass. Only little attention has been paid to this vital issue, which has restricted the practical applications of cold-bonded LWAs. More recently, Hwang and Tran [11] have applied hydrogen peroxide as a foaming agent, in order to generate more pores inside the aggregate for the purpose of reducing its density. They have reported that the lowest oven dry specific gravity of 1.27 g/cm^3 was achieved when a composition of 80 wt-% fly ash and 20 wt-% GBFS was used, with a foaming agent concentration of 7 wt-%. Though this approach decreased the particle density of cold-bonded LWAs, it was still higher than that of sintered LWAs. A novel cold-bonded production method is therefore required, in order to satisfy three main criteria: low particle density, good mechanical properties and an effective solution for recycling waste materials.

The main objectives of this research can be outlined as follows: (1) optimizing a cold-bonded method for producing artificial LWAs, with low density and good mechanical properties. In this study, a lightweight aggregates with core-shell structure were produced by the encapsulation of expanded perlite particles within a cover matrix composed of cement and fly ash; (2) investigation of the effects of different parameters (cement content, speed and angle of pelletizer disc) on the aggregate properties, in order to determine the optimum values of these parameters; (3) utilization of expanded perlite powder (EPP) as a way to reduce the particle density of the manufactured aggregate, to less than 1 g/cm^3. To achieve this aim, EPP was incorporated in the shell structure as a partial replacement of fly ash. A variety of tests were conducted to evaluate the effect of EPP content on the mechanical and microstructural properties of the manufactured aggregate; and (4) detection and comparison of the pozzolanic activity of fly ash and EPP as mineral admixtures in cement paste, to fully understand the positive impact of EPP on the aggregate characteristics.

2. Methodology

Lightweight aggregates were produced by encapsulating expanded perlite particles within a shell structure as shown in Fig. 1. The encapsulation process was performed using a pelletizer disc, 40 cm in diameter and 10 cm in depth (Fig. 3). In this study, two groups of LWAs were manufactured. In the first group, expanded perlite particles (EP), with a size ranging from 2 to 4 mm, were encapsulated in a cover matrix composed of cement and fly ash. A total of 24 samples with three variable parameters were produced: the cement content of the cover matrix, speed and angle of the pelletizer disc. The performance of the aggregate was evaluated according to standard tests, in order to ascertain the optimal values of these parameters. Next, in the second group, expanded perlite powder (EPP) with a size <125 μm was incorporated into the manufacturing process. It was used in the cover matrix as a partial replacement of fly ash. Here, five aggregate samples were prepared, differing only in their EPP content, with the other parameters kept fixed at their estimated values. A variety of tests were conducted to evaluate the effect of EPP on the properties of the aggregates.

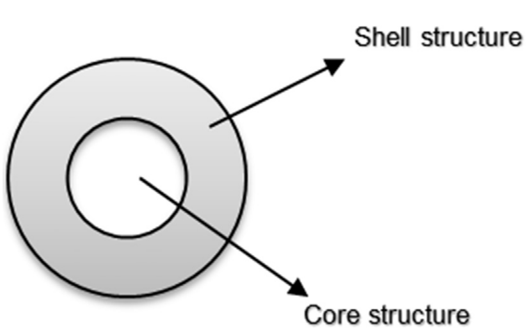

Fig. 1. Schematic diagram on the formation of core-shell structured LWAs.

3. Experimental investigation

3.1. Materials

In this research, ordinary Portland cement (OPC, CEM I 42.5R), provided by CEMEX (Germany), and class F fly ash EFA-Füller HP, obtained from BauMineral (Germany), were used. Both the expanded perlite and expanded perlite powder were supplied by KLEIN (Germany). The loose bulk densities of EP and EPP were measured according to EN 1097-3, being 80 and 112 kg/m^3, respectively. The physical properties and chemical compositions of the materials used are listed in Table 1. The specific surface area and specific density were determined using Brunauer-Emmett-Teller (BET) analysis and Helium pycnometry, respectively. Fig. 2 shows the particle size distribution of cement, FA and EPP, as measured by laser granulometry.

3.2. Production of LWAs

A total of 24 LWA_{X-A-S} were produced by encapsulating EP particles within a cover matrix composed of cement and FA into the pelletization disc, where X refers to the cement content of the cover matrix (wt-%), and A and S refer to the angle (°) and rotation speed (rpm) of the disc, respectively. After several manufacturing trials and in consideration of production efficiency, two angles (35° and 40°), and three speeds (20, 30, and 40 rpm) were selected. Four different cement to fly ash ratios were used in the mixture of the cover matrix; 5:95, 10:90, 15:85, and 20:80. The amounts of both the EP particles, as a core structure, and the powder mixture as a shell structure, were based on the production of aggregates with a size range of 4–8 mm and a shape as close to spherical as possible. As such, for each production process, 25 g of EP particles were first placed into the pelletizer disc. Thereafter, they were simultaneously sprayed with water and fed with 1000 g of dry mixture. The water content was about 120 ± 10*g* (12 ± 1 wt-% of the mixture). The water was sprayed carefully during the encapsulation process, in parallel with the feeding of the powder. The total pelletization time was about 15 min. At the end of the manufacturing procedure, the fresh pellets were carefully discharged from the device and directly placed and kept in sealed bags at a temperature of 21 ± 1 °C for 24 h. Next, the samples were cured under water until testing day. Afterwards, the hardened LWAs were sieved and particles with a size range of 4–8 mm were selected for the tests. The manufacturing process as well as the fresh pellets are shown in Fig. 3.

3.3. Influence of production parameters on aggregate properties

Data obtained in previous studies [5,9,12] has indicated that the angle and speed of the pelletizer disc, as well as the binder content, substantially affect the properties of the manufactured aggregate.