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Use of bottom ash and stone dust to make lightweight aggregate

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HIGHLIGHTS

- Artificial lightweight aggregate was produced with by-products from other industry.
- 80–20% of stone dust to bottom ash was used as the main materials.
- 5% of Na_2SO_4 was used for flux.
- 10% of oxidizing slag was used for bloating agent.

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ABSTRACT

The objective of this study is to describe how by-products of bottom ash and stone dust can be converted to lightweight concrete aggregate; both stone dust and bottom ash have a chemical composition ideal for use as expansive lightweight aggregates. This study determined the optimum proportion of bottom ash and stone dust. Bloating agents and fluxes such as Na_2SO_4, Na_2CO_3, $CaSO_4$, $CaCO_3$, and NaOH along with glass abrading sludge, Fe_2O_3, blast furnace slag, and oxidizing slag were tested to determine the optimal properties of manufactured lightweight aggregate products. Furthermore, the type of furnace needed for production and the sintering temperature required for the materials was tested and determined. This study also determined that an oven-dried density of 1.46 g/cm^3 with an absorption ratio of 8.5% can produce lightweight aggregates ideal for use as a lightweight concrete for structural usages.

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1. Introduction

Industrial waste, also known as production by-products, have been investigated extensively for sustainable alternatives to Portland cement in concrete. From the power plant, fly ash and bottom ash are obtained, and fly ash is widely used as a well-known supplementary cementitious material for improving workability and durability of concrete. Fly ash has been used in concrete production for several years; however, bottom ash is still treated as a waste and is put in impoundment ponds, silos or landfills. Bottom ash is sometimes used in asphalt mixes, but pyrite contamination can make it undesirable for main roads. It cannot be a popular choice. However, it can be a sustainable component of concrete [1–5]. Andrade et al. [6] found that bottom ash in its current form can replace fine aggregate, and Zhang et al. [7] reported improved mechanical properties of concrete with cement replaced bottom ash powder's filler effect. Most recently, bottom ash was continuously studied as a replacement of fine aggregate and coarse aggregate [8]. Unlike to fine aggregate, by Zaetang et al. [9], the porous particle of bottom ash was used as the coarse aggregate for pervious geopolymer concrete. Similarly, using the porous properties of bottom ash, Sun et al. [10] suggested to improve the bottom ash treatment process from wet-process to dry-process and tried to produce lightweight aggregate with the dry-bottom ash. During the process of crushing aggregates, stone dust is produced which is referred to as crusher fines, dust of fracture, or micro fines. Although there are a few studies on using this stone dust as a concrete filler [11], there is not enough research on utilizing the stone dust and most stone dust is wasted.

Lightweight concrete is advantageous for structures requiring a low dead load [12], and it is produced using lightweight aggregates, which can either be natural or artificial. Artificial lightweight aggregate is known for its stability and is mainly manufactured by a bloating process when gas is produced during the sintering process at 1000–1200 °C. Commonly used materials for artificial lightweight aggregate which can produce enough gas for bloating are summarized by Riley [13]. For producing artificial lightweight

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aggregates, by-products such as scrap tire rubber, fly ash aggregate, sintered sewage sludge ash, incinerator bottom ash, and waste glass are used as the materials [14–21] based on the chemical composites for bloating. Additionally, regarding the properties, the lightweight aggregate should be of low density for its original purpose of reducing the weight of structures. To achieve low density, the inner structure of lightweight aggregate can be porous, which is required of aggregates used in light weight concrete; however, high absorption ratios of aggregates is not favorable. Therefore, the artificial lightweight aggregate should produce enough gas or air during the bloating process for the low density, and still produce enough viscosity to entrap the gas and prevent an excessively high absorption rate of the aggregate. Hence, depending on the different composites, sintering temperature should be controlled. Also for bloating mechanisms during the sintering process, flux and gas producing additives (hereafter referred to as bloating agents) influence on temperature and the final properties of the aggregate [22,23].

In this study, the production technique for making artificial lightweight coarse aggregate with bottom ash and stone dust is suggested. Depending on the purpose of different by-products and their compositions, the production of lightweight aggregates must be checked for favorable quality. Additionally, the possibility of other by-products was considered based on the flux and bloating agents. The result of this study is expected to contribute to the improvement of artificial lightweight aggregates through a production method that uses industrial by-products for base materials and bloating agents. Especially, the technique suggested in this research is considered to contribute on enhancing the recycling method for bottom ash and stone dust.

2. Experimental study

2.1. Experimental plan

As a successful lightweight aggregate, the target properties was decided to achieve less than 1.5 g/cm^3 of oven-dried density and less than 10% of absorption rate. To achieve these target properties, the experiment conducted consisted of two phases: (1) determining optimum proportion of bottom ash and stone dust and (2) selecting the best performing flux and bloating agent. Also depending on the conditions which were subject to change such as proportions and kinds of flux and bloating agents, the sintering temperature was also changed and evaluated to attain the most suitable conditions.

Phase 1 of the research was based on selecting the appropriate proportion of bottom ash and stone dust and the type of furnace and sintering temperature was determined. A box furnace and rotary tube furnace were selected for use in the experiments. The proportions of stone dust and bottom ash were prepared in five different stone dust-to-bottom ash proportions: 2:8, 4:6, 6:4, and 8:2. Applied sintering temperatures were 1100 and 1150 °C with 15 min of sintering time. The sintering time of 15 min was determined from preliminary test result. The properties of manufactured lightweight aggregate were measured to determine oven-dried density and absorption rate. Other conditions regarding preparation and production the lightweight aggregate are discussed in Section 2.2.

Phase 2 was devoted to selecting the correct flux and evaluating different properties of the lightweight aggregate depending on various fluxes based on the base materials of the determined proportion from the first phase of the experiment. The prepared fluxes were Na_2SO_4, Na_2CO_3, $CaSO_4$, $CaCO_3$, NaOH, and glass abrading sludge created during the surface processing of flat glass. Each flux was selected based on the chemical composition and replaced with 5%, 10%, 15%, and 20% for Na_2SO_4, Na_2CO_3, $CaSO_4$, and $CaCO_3$; 1%, 3%, and 5% for NaOH, and 10%, 20%, and 30% for glass abrading sludge according to the mass of the base material were also used. The furnace used was the one selected from furnace type from Phase 1. Since the flux provides better conditions inside the furnace, the sintering temperature was tested based on the types of flux with the range from 850 °C to 1200 °C to prevent agglomeration between the aggregates in the furnace at certain ranges of sintering temperature depending on the flux materials. The sintering time was fixed at 15 min, and the properties of manufactured lightweight aggregate were examined for oven-dried density and absorption rate. In addition to the flux types, bloating agents were also selected. Based on the selected flux material, three different bloating agents of Fe_2O_3, blast furnace slag, and oxidizing slag were prepared and the property change was evaluated. Depending on the different bloating agents, different amounts and ranges of sintering temperature were applied as shown in Table 1. The oven-dried density and absorption rate of manufactured lightweight aggregate were measured and compared to select the optimum conditions. The physical properties of the manufactured lightweight aggregate were measured following the ASTM C127 [24] standard method.

The production process of the lightweight aggregate is started with oven drying the stone dust and bottom ash over 24 h at 105 °C to remove moisture. Using the ball mill, each material was milled to less than 100-micron particle size and mixed according to designated proportions.

2.2. Materials and sample preparations

To manufacture the lightweight aggregate, in this study, an expanded type of lightweight coarse aggregate was targeted. The expansive lightweight aggregate should contain appropriate chemical composites of silicon dioxide and aluminum oxide which were mainly summarized in former research as defined by Riley in [13]. The stone dust and bottom ash used were obtained from a Korean aggregate production company and a power plant, respectively. Each chemical composite is in Table 2 which shows both materials containing a large portion of SiO_2, Al_2O_3, and Fe_2O_3, which are best suited for producing expansive lightweight aggregates. For the flux and bloating agents, except for chemical compounds, each material was obtained as a byproduct from a Korean flat glass manufacturing company and a steel mill for the glass abrading sludge and oxidizing slag, respectively. The blast furnace slag used was a commercially available product in Korea. The chemical compositions of these materials are summarized in Table 3.

The mixed materials were shaped with a tube-type pelletizer, which had a 10 degree tilt and 40 rpm rotation speed. Aggregates were pelletized to a coarse aggregate size of 20 mm. The pelletized material was oven-dried and sintered for 24 h at 105 °C to remove the moisture added during the pelletizing process. Preliminary testing determined the amount of water needed for pelletizing.

A box furnace and rotary tube furnace were used for testing. The box furnace used electricity as an energy source. The temperature of the box furnace was increased in two steps: (1) Setting a temperature of 400 °C for 20 min during the preliminary sintering process and (2) setting a designated temperatures of 15 min for the main sintering process. The rotary tube furnace had a kiln which was one meter in length and could be tilted and rotated according to designated angle and speed. From the preliminary test results, we determined that 4 rpm with 0.9 degree tilting of the kiln provided best results with a 15-min run time to pass through the kiln.

3. Results and discussion

3.1. Determining materials proportions

The oven-dried density and absorption rate of manufactured lightweight aggregates depending on the different types of furnaces and different proportions of materials are shown in Figs. 1 and 2. Generally, the rotary tube furnace produced lower oven-dried density and higher or similar absorption rates than the box furnace. The lower density of manufactured lightweight aggregate from the rotary tube furnace was attributed to the flow of oxygen through the both ends of the furnace. This conclusion is based on the high concentration of oxygen, which created good conditions for reduction and, thus, produced a low density aggregate. Depending on the proportions of the materials, as the portion of stone dust was increased, the oven-dried density increased and the absorption rate decreased. This is assumed to be due to a decrease in the amount of Al_2O_3 according to the decreased portion of bottom ash and the increased amounts of CaO and Na_2O, which occurred with the addition of stone dust. The addition of stone dust also caused the melting point and viscosity to decrease. Higher sintering temperatures increased material melting, thereby increasing the density as well as the portion of black core inside the aggregate (Fig. 3 shows the black core of the aggregate).

However, at 1150 °C, some aggregates agglomerated together, and this agglomeration affected over 40% of the stone dust in the box furnace and over 80% of the stone dust in the rotary tube furnace. As a result, the rotary tube furnace was selected as the best choice for further production of lightweight aggregate with a lower density product created at 1100 °C sintering temperature. For the proportion of the materials, stone dust to bottom ash ratios of 6:4 or 8:2 were selected as the best proportions for satisfying both low density and low absorption rates. However, still the properties of the lightweight aggregate with stone dust and bottom ash

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