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A study of the properties of foamed lightweight aggregate for self-consolidating concrete

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HIGHLIGHTS

- Foamed lightweight aggregate (FLWA) with addition foaming agent was produced.
- Effects of foaming agent and surface treatment on properties of FLWA were assessed.
- FLWA was used as coarse aggregate for production of SCC.
- Workability and strength of SCC with FLWA were investigated.

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ABSTRACT

This study investigated foamed lightweight aggregate (FLWA) manufactured with hydrogen peroxide (HP) as a foaming agent and using cold-bonded agglomeration process, a relatively low-polluting, energy efficient method of FLWA production. A number of the types of produced FLWA were surface treated to improve the performance of the aggregates. Moreover, 8 types of FLWA were used as coarse aggregate to produce self-consolidating concrete (SCC). A variety of tests were conducted to evaluate the effects of the foaming agent and the surface treatments on the properties of the cold-bonded lightweight aggregate. The workability, unit weight, and strength of the SCC specimens were determined in accordance with established standards. The FLWA type with the lowest specific gravity was binary mixture of 80% fly ash (FA) and 20% ground blast furnace slag (GBFS) at an HP concentration of 7%, which a specific gravity 1.27. The flowability, viscosity, and passing ability of all SCC mixtures met EFNARC requirements. Finally, the findings support that using foaming agent and modifying the surface of FLWA significantly affects the strength of SCC.

1. Introduction

Excessive density is a key problem of conventional concrete and the weight of concrete is typically an important factor in strength calculation for concrete structures. Furthermore, concrete production requires significant inputs of natural resources such as sand, and stone. In many development countries, the demand for cement, sand, and stone has increased rapidly to meet needs of building factories and other structures, leading to increased damage to the environment and depletion of limited natural resources.

Using pozzolanic materials (i.e. fly ash, ground blast furnace slag) from industrial-production waste to make concrete is one possible approach to resolving this problem. One pozzolanic material, fly ash (FA), is a waste product of powdered coal that has been burned as fuel in power plants. FA is regularly available from coal-burning power plants with the advantages of low cost and low specific gravity. Using FA as main material for production of lightweight aggregate (LWA) to replace coarse aggregate in concrete has attracted significant researcher attentions. A variety of techniques such as cold bonding and sintering may be used to produce fly ash LWA [1–7]. Sintered LWA is produced mainly at high temperatures up to 1200 °C [3]. The significant energy consumed and the pollution generated by this method has rendered it unfeasible for commercial use [5]. Conversely, cold-bonded LWA produced using the agglomeration technique and consumes relatively low level of energy. Therefore, cold-bonded LWA better meets the needs of concrete construction in terms of being sustainable and environment friendly.

Cold-bonded LWA has been manufactured by using FA with the addition of GBFS, cement, and the activators, such as sodium hydroxide, sodium silicate, and aluminum hydroxide [1,2,5,8,9].

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The results show that, although the specific gravity of cold-bonded LWA has been decreased, it remains significantly higher than that of sintered LWA. Efforts to date to meaningfully lower the specific gravity of cold-bonded LWA have been unsuccessful. Moreover, cold boned LWA exhibits higher water absorption, which negatively affects concrete quality. Thus, developing a viable cold-bonded LWA that exhibits considerably improved characteristics in terms of the specific gravity, water absorption, and strength is a challenge for researchers.

Research on cold-bonded LWA has also recently been done on the application of this material in lightweight concrete (LWC) and self-consolidating concrete (SCC). Baykal and Döven [7] reported that the average fresh and oven-dry unit weight of concrete produced from artificial fly ash aggregates are 1.85 and 1.50 t/m^3, respectively and that LWA concrete reached maximum compressive strength of 33 MPa at 28-day age. In particular, SCC produced from cold-bonded LWA has been reported to be the most workable and durable. The mix proportions of self-consolidating lightweight concrete (SCLWC) by Densified Mixture Design Algorithm (DMDA) method demonstrated high strength, flowability and durability [10]. Additionally, the spherical shape of cold-bonded LWA facilitated the flowability of SCC, while increasing of LWA content reduced the volume of superplasticizer (SP) [11,12]. Moreover, incorporating mineral admixtures such as fly ash, and silica fume has been demonstrated to improved the fresh properties of SCC produced with cold-bonded FA lightweight aggregate [13]. Nevertheless, a few studies have provided comprehensive data regarding the workability and mechanical properties of self-consolidating concrete that use cold-bonded fly ash LWA as coarse aggregate.

The aim in this research was to investigate the manufacturing and properties of cold-bonded fly ash LWA with the addition of HP as a foaming agent and surface treatment. Eight kinds of foamed lightweight aggregates (FLWA) were used as coarse aggregates to make self-consolidating concrete samples for use in comparison. The workability and strength of resultant SCC was assessed in accordance with relevant standards.

2. Experiment

2.1. Materials and production of foamed lightweight aggregate

Type I cement, Class F fly ash, and ground blast furnace slag produced in factories located in Taiwan were used as the main material to produce the FLWA in this study. Physical properties and chemical compositions of cement, FA and GBFS are as shown in Table 1. Hydrogen peroxide (concentration: 35%; specific gravity: 1.196) produced by First Chemical Company was used as the foaming agent.

Previous studies have shown that the dissolved proportion of silica in FA increased with present of alkaline activators [1,14]. This research used a combination of sodium silicate (Na_2SiO_3; Na_2O: 8.26%; SiO_2: 25.7%; water: 66.04%) and sodium hydroxide (NaOH) with a purity of >98% by weight as the alkaline activator, which energized the activation of FA and GBFS. Additionally, the molar SiO_2/Na_2O of 1.5 was selected to produce an alkaline solution of Na_2SiO_3 and NaOH 10 M.

The FLWA in this study was produced using the cold-bonded agglomeration process. To manufacture the spherical pellets, a pelletizing disc of 80 cm in diameter and 30 cm in depth was run at constant angle and speed in accordance with procedure used in previous research [1]. Two dry mixtures, a binary mixture of 80% FA + 20% GBFS (denoted as the F8S2) and a ternary mixture of 70% FA + 20% GBFS + 10% cement (denoted as the F7S2C1), were used to produce the FLWA. Moreover, a sprayed solution with 35–40% total materials by volume was used as wetting agent and coagulant to form fresh pellets with motion of rolling disc that consisted. For dry mixtures without cement, this solution comprised a 50% alkaline solution and a 50% HP solution. For dry mixtures with cement, this solution comprised a 50% HP solution and 50% water. As shown in Table 2, concentration levels in the HP solutions made from the combination of the HP and water ranged from 0–8.75% to permit an evaluation of the influence of foaming agent on the properties of the FLWA. After pelletization, fresh particles were kept in a curing room at 23 °C and a relative humidity of 60%. On 28-day curing age, the desired fractions of aggregates were selected in the range of 4 mm to 10 mm in order to test the properties of the FLWA and to use as coarse aggregate for casting SCC.

2.2. Surface treatment of lightweight aggregate

Because FLWA exhibits higher water absorption and lower strength, this study treated the surface of FLWA with an alkaline solution to reduce the former and increase the latter. The alkaline solution was made with a molar SiO_2/Na_2O of 2.5 and an amount of 5–7% aggregates by weight. First, FLWA was introduced onto the pelletizing disc, which was rotated at a constant speed. Second, the alkaline solution was continuously sprayed through an electric spray gun onto the surface of the foamed lightweight particles for 7–10 min. Finally, the aggregates were removed from the disc and cured at an ambient temperature.

2.3. Materials and production of self-consolidating concrete

In this study, the SCC was produced using Type I cement and Class F fly ash as binders. A superplasticizer (SP) that was brown in color with a specific gravity of 1.1 and a pH of 6–8 was used to maintain the level of workability required under EFNARC for fresh concrete mixtures [15]. In addition, tap water was used as the mixing water. Crushed sand of 4.75 mm maximum size and a density, fineness modulus, and water absorption of 2650 kg/m^3, 3.0, and 1.37%, respectively, was used to produce the SCC.

Eight types of FLWA were selected from the produced FLWA and applied as coarse aggregates to produce SCC with a water-to-binder ratio of 0.3 in order to investigate the effects of FLWA on the properties of SCC. The DMDA method was used to calculate the mix proportions for the SCC with the different types of FLWA [1,10,16]. Hwang and Hung [10] reported that using that DMDA method enhances the performance of SCC. Table 3 shows the composition of the 8 mixtures. To address the high water absorption of FLWA, previous studies have suggested

Table 1
Chemical and physical properties of cement, FA and GBFS.

Items	Cement	Class F fly ash	GBFS
Chemical properties			
SiO_2 (%)	22.01	63.9	39.2
Al_2O_3	5.57	20.2	13.0
Fe_2O_3	3.44	6.5	0.2
CaO	62.80	3.8	37.5
MgO	2.59	1.1	7.1
SO_3	2.08	1.4	2.0
TiO_2	0.52	1.2	0.5
P_2O_5	0.05	0.5	–
Na_2O	0.40	–	–
K_2O	0.78	1.1	0.2
Free CaO	1.05	–	–
C_3S	40.10	–	–
C_2S	32.80	–	–
C_3A	8.90	–	–
C_4AF	10.50	–	–
Physical properties			
Fineness (cm^2/g)	3460	3120	4330
Specific gravity	3.15	2.2	2.86

Table 2
Types of foamed lightweight aggregate.

Type of FLWA	FA (%)	GBFS (%)	Cement (%)	Concentration of HP (%)	Surface treatment
H0F8S2	80	20	0	0	N
H3.5F8S2	80	20	0	3.5	N
H5.25F8S2	80	20	0	5.25	N
H7F8S2	80	20	0	7	N
H8.75F8S2	80	20	0	8.75	N
H0F8S2-ST	80	20	0	0	Y
H7F8S2-ST	80	20	0	7	Y
H0F7S2C1	70	20	10	0	N
H3.5F7S2C1	70	20	10	3.5	N
H5.25F7S2C1	70	20	10	5.25	N
H7 F7S2C1	70	20	10	7	N
H8.75F7S2C1	70	20	10	8.75	N
H0F7S2C1-ST	70	20	10	0	Y
H7F7S2C1-ST	70	20	10	7	Y

HP: hydrogen peroxide; H7: hydrogen peroxide concentration of 7%; F8: 80% fly ash; S2: 20% ground blast furnace slag; C1: 10% cement; ST: surface treatment; N: none; Y: yes.