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Strength and permeability properties of self-compacting concrete with cold bonded fly ash lightweight aggregate

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HIGHLIGHTS

- Cold bonded fly ash lightweight aggregates (LWA) were manufactured by pelletization.
- SCC with partial replacement of LWA with natural aggregate were produced.
- Binary and ternary blends of fly ash (FA) and silica fume (SF) were utilized for SCC.
- Compressive strength and some permeability properties were tested at different ages.
- Significant enhancement levels were observed depending on the mix compositions.

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ABSTRACT

This paper presents the results of an experimental study on the hardened characteristics of the self-compacting concretes made with cold bond fly ash lightweight aggregates. Binary and ternary use of fly ash (FA) and silica fume (SF) blends have been considered in the production of self-compacting cold bonded fly ash lightweight aggregate concretes (SCLWCs). For this, a total of 9 SCLWC mixtures were proportioned having constant water–binder ratio of 0.35 and the total binder content of 550 kg/m^3. The control mixture contained only Portland cement (PC) as the binder while the remaining mixtures having binary and ternary blends of PC, FA, and SF. Properties that include compressive strength and ultrasonic pulse velocity, chloride ion penetration, gas permeability, water absorption by total immersion and by capillary absorption were investigated at two curing ages of 28 and 56 days. Test results have showed that incorporating the mineral admixtures enhanced significantly the permeability characteristics. Moreover, it was observed that the compressive strength of the SCLWCs with SF was much higher than those of the control concrete.

1. Introduction

For many years ago, the lightweight aggregate has been used for the structural purposes. They are normally employed in structures for which the dead load participates in the major part of the total load. Various types of lightweight aggregates such as expanded clay and sintered fly ash can be produced through heat treatment from 1000 to 1200 °C [1]. An alternative way of producing lightweight aggregate with minimum energy consumption is the method of agglomeration of fly ash particles by cold-bonding process, where the water is the wetting agent acting as coagulant, so that the moist mixture would be pelletized in a tilted revolving pan. Lime and Portland cement used as binder. By using such aggregates, structural lightweight concrete (LWC) with 28-day compressive strength up to 30 MPa has been produced [2,3].

Low unit weight, higher adhesion between reinforcing steel and concrete, enhancement in some durability characteristics, are special properties of LWCs that make it obviously different from normal weight concrete (NWC) [4–6]. The wide variety of the lightweight aggregate source and producing method result in distinguishing behavior among the LWCs. Thus, properties of LWCs have to be examined individually for every sort of lightweight aggregate [7].

Incorporations of mineral and chemical admixtures in the conventional concrete has lead to emergence of new trends in concrete related studies to improve the strength and durability [8]. Thus, at the end of the eighties, self-compacting concrete (SCC)

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characteristics have been achieved for tailored preparations by Japan. Its investigation represents a major technological advance which led to a better quality of concrete and higher productivity [9]. SCC is characterized by the high fluidity under its own weight such that it can be placed without vibration, easily fill small intersects of formwork and it can be pumped through long distances [10]. In the production of self-compacting concrete, coarse aggregate content is restricted and generally mineral and chemical admixtures are used. A number of studies have been reported in the literature concerning the use of mineral admixtures to enhance the self-compacting characteristics of the concrete [9–11]. Permeability is of importance for the structures under severe environmental effects such as freezing–thawing and chemical attacks. Therefore, transport properties of concrete play an important role in a wide variety of processes of environmental and technological concern. In recent years, some researchers have been investigating the gas permeability of concrete in order to evaluate the pore structure [12,13]. In recent years, investigation of durability properties of concretes produced with cold bonded fly ash aggregates has attracted the interests of the researchers [14–18].

The properties of the lightweight concretes mainly depend on the amount and the properties of the lightweight aggregates used. Such that, number of studies have been conducted to examine how the aggregate properties affect the mechanical properties of lightweight aggregate concrete. However, majority of investigations focused on a few types of lightweight aggregates. Cold-bonded fly ash aggregates have been easily used in the production of concretes but, its usage in the production of self-compacting concretes has not obtained enough attention in the literature especially when binary and ternary blends of FA and SF are incorporated as mineral admixtures with different replacement levels. Therefore, to achieve more sustainable and environment friendly concretes, the use of fly ash lightweight aggregates may be an alternative to conventional concretes.

There are some studies in the literature studying fresh properties of self compacting light weight concretes (SCLWC). Kim et al. [19] used two types of lightweight coarse aggregates and determined characteristics of self-consolidating concretes. In the study of Wu et al. [20] the workability of SCLWC was investigated. Choi et al. [21] investigated fluidity and mechanical properties of high-strength SCLWC. The fresh properties of SCLWC containing expanded polystyrene was investigated by Madandoust et al. [22].

In this study, an extensive experimental investigation was performed to demonstrate the compressive strength and ultrasonic pulse velocity, chloride ion penetration, gas permeability, water absorption by total immersion and by capillary rise behavior of self-compacting cold bonded fly ash lightweight aggregate concrete (SCLWC) mixtures with different level of replacement of fly ash (FA) and silica fume (SF). Cold bonded fly ash aggregate was utilized as coarse aggregate. A total of 9 different SCLWC mixtures were proportioned having constant water–binder ratio of 0.35 and the total binder content of 550 kg/m^3. The control mixture contained only Portland cement (PC) as the binder while the remaining mixtures incorporated binary and ternary blends of PC, FA, and SF. Based on the test results, the effects of FA and/or SF upon concrete properties were discussed. In the literature, there is a dearth of research related to the use of the cold bonded fly ash lightweight aggregate in the production of SCC.

2. Experimental investigation

2.1. Materials

The SCLWC mixtures produced in this study were prepared with CEM-I 42.5 PC, a Class F FA, and SF. The chemical and physical properties of the cement and mineral admixtures used are shown in Table 1. A mixture of crushed limestone and natural river sand was used with a maximum size of 5 mm. The fineness modulus of the crushed sand and natural river sand were 2.57 and 2.87, respectively. The specific gravity values are 2.45 for the former and 2.66 for the latter, respectively. The particle size distributions of the fine aggregates are presented in Table 2.

Table 1
Chemical composition and physical properties of cement and mineral admixtures.

Chemical analysis (%)	Portland cement	Silica fume	Fly ash
CaO	62.58	0.45	4.24
SiO_2	20.25	90.36	56.2
Al_2O_3	5.31	0.71	20.17
Fe_2O_3	4.04	1.31	6.69
MgO	2.82	–	1.92
SO_3	2.73	0.41	0.49
K_2O	0.92	1.52	1.89
Na_2O	0.22	0.45	0.58
Loss on ignition	2.99	3.11	1.78
Specific gravity	3.15	2.2	2.25
Specific surface (cm^2/g)	3260	210,800	2870

Note: 1 cm^2/g = 0.48843 ft^2/lb.

Coarse cold-bonded fly ash lightweight aggregates were used in the production of the self compacting concrete. A dry mixture of 10% CEM I Portland cement and 90% fly ash by weight was pelletized through wetting in a rotating and 45 angle tilted pan at ambient temperature. Water was sprayed onto the Portland cement-fly ash powder mixture during the first 10 min to act as coagulant in the pelletization process. For further stiffening the fresh pellets the agglomeration process was prolonged for additional 10 min. Afterwards, the fresh pellets produced were put in plastic sealed bags and stored for the hardening in curing room at temperature of 20 °C and 70% relative humidity for 28 days. The artificial aggregates were sieved at the end of the curing periods. The aggregates passing 16 mm sieve and retaining on 4 mm sieve were used as a coarse aggregates. Specific gravity of the aggregates was 1.92 at SSD condition, and the water absorption at 24 h was 12.7% by weight. The methods used in measuring are according to ASTM C 127 [23]. The schematic illustration of the aggregate production is presented in Fig. 1, whereas Fig. 2 exhibits photographic view of a stack of the produced aggregate. To achieve the desired workability in all concrete mixtures, a polycarboxylic ether type superplasticizer (SP) with a specific gravity of 1.07 was employed.

2.2. Concrete mixture proportioning and casting

A total of nine mixtures were designed having a constant water–binder ratio of 0.35 and total cementitious materials content of 550 kg/m^3. The mixtures were prepared with cold-bonded lightweight coarse aggregates covering 50% by volume of the total aggregates in the mixture, and the remaining 50% of the total aggregates volume were occupied by natural and crushed sand aggregates. The control mixture included only ordinary Portland cement as the binder, whereas the remaining mixtures incorporated binary (PC + FA, PC + SF); and ternary (PC + FA + SF) cementitious blends in which a proportion of PC was replaced with the mineral admixtures. The replacement ratios for FA were 15% and 30%, while the replacements of SF were 5% and 10% by weight of the total binder content.

In order to eliminate the early slump loss due to high absorption capacity of the lightweight fly ash aggregates the following procedure was adopted. Lightweight fly ash aggregates were first immersed in water for 30 min and afterwards laid on a dry trowel for drying the aggregates manually by hands to a saturated surface dry (SSD) condition. Laboratory mixing pan was used in concrete mixing. First of all SSD lightweight aggregate was mixed with the binder then the natural sand and crushed sand was added to the mixer. After the homogenizing of the aggregates and the binder after 30 s of mixing, about one third of the mixing water was added slowly into the mixer and continuing to mix for one more minute. Finally, the superplasticizer with remaining water was introduced, and the concrete was mixed for 3 min and

Table 2
Sieve analysis and physical properties of the fine aggregates.

Sieve size (mm)	Fine aggregate	
	River sand	Crushed sand
8	100	100
4	86.6	95.4
2	56.7	63.3
1	37.7	39.1
0.5	25.7	28.4
0.25	6.7	16.4
Fineness modulus	2.87	2.57
Specific gravity	2.66	2.45

Note: 1 mm = 0.0393 in.