Construction and Building Materials 77 (2015) 276–287

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Accelerated curing effects on the mechanical performance of cold bonded and sintered fly ash aggregate concrete

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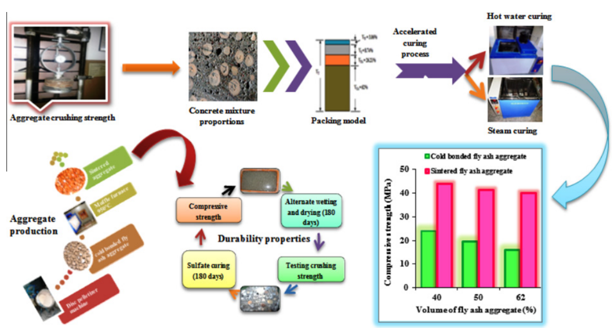
HIGHLIGHTS

- Improving the stability of fresh cold bonded aggregate using alkali activator.
- Comparative assessment on the physical and mechanical properties of cold bonded aggregates.
- Maximum utilization fly ash aggregate concrete and its effect on the mechanical properties of concrete.
- Effect of accelerated curing techniques on the strength gain properties of fly ash aggregate incorporated concrete.
- Systematic evaluation of various durability properties of fly ash aggregate concrete mixes.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 27 August 2014
Received in revised form 7 December 2014
Accepted 28 December 2014
Available online 12 January 2015

Keywords:
Fly ash
Bentonite
Pelletizer
Hot air oven
Alkali activator
Cold bonded aggregate
Sintered aggregate
Sorptivity
Steam chamber
Hot water curing

ABSTRACT

This study investigates the mechanical performance of concrete incorporating fly ash based light weight aggregates. Comparative assessment on the physical and mechanical properties of cold bonded and sintered fly ash aggregates were evaluated systematically. Design concrete mixes were theoretically arrived using aggregate packing concept with different combinations of two phase system (mortar and fly ash aggregate). Experimental test results indicated favorable mechanical strength improvements of concrete incorporating sintered fly ash aggregates compared to cold bonded aggregates. Test results also demonstrated that the composite strength of concrete was found to be improved when the ratio of volume of coarse aggregate to volume of cement mortar is lower. Most notably, the sintered fly ash aggregate (62%) substituted concrete mixes exhibited a maximum compressive strength of 39.97 MPa when subjected to hot water curing. In general, favorable strength gain properties were noted in the case of fly ash aggregate concrete specimens exposed to either accelerated steam or hot water curing. Effects on the strength properties of various fly ash aggregate concretes subjected to various durability tests were also reported in this study.

1. Introduction

Fly ash waste generated from thermal power plant poses huge problems due to large scale disposal. This can be eliminated by its large scale utilization in construction industry as a filler mate-

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http://dx.doi.org/10.1016/j.conbuildmat.2014.12.108
0950-0618/

rial in concrete. Fly ash was successfully used in concrete either as cementitious replacement or as aggregate fillers. Artificial lightweight aggregate finds potential applications in lightweight concrete structures and such aggregates were produced from the cold-bonding of fly ash. Significant studies had been conducted in the past towards developing a cost effective method for producing artificial lightweight aggregate using fly ash at low energy consumption [1–3]. Production methods such as disc pelletizer and briquette compaction technique were used widely in many studies for mass production of aggregates using fly ash [4,5]. Hardening process of fly ash aggregates involves two stages: cold bonding by means of air drying at normal room temperature and further sintering (burning) at higher temperature. As evident from earlier studies that, cold-bonded aggregates produced from class-C fly ash were stronger and stable compared to class-F fly ash. This necessitates the addition of chemical activator to improve the cold bonding of class-F fly ash aggregate [6]. The improvement on strength properties was investigated with the addition of binders such as slag, bentonite and metakaolin which proved to be successful for efficient binding during agglomeration of aggregate formation [7,8]. These are primarily used to improve the stability of aggregate production and faster strength gain when subjected to sintering process [6]. The presence of silica and alumina in the source material undergoes glass transition phase and provides fusion of Si–O–Al particles resulting in improved hardened aggregate properties [9]. Mix design procedure for conventional aggregate concrete has a deterministic procedure to obtain a required target strength and workability. However, the lightweight concrete mix design is governed by a careful mix design procedure as the aggregates are inherently porous which requires an initial saturation and further increase the water demand for obtaining a desired workability [10–12]. Studies showed that the appropriate mix design developed for light weight concrete containing different saturated conditions of lightweight aggregate can exhibit a compressive strength greater than 40 MPa. Also, the development of a novel vacuum saturation procedure was found to be efficient for saturating the light weight aggregates to improve the fresh concrete properties [13,14]. The sufficient curing of light weight aggregates after production is essential for showing an improved performance when incorporated in concrete. Lightweight aggregate concrete specimen subjected to accelerated steam curing exhibited higher compressive strength when compared to sealed and air cured concrete specimen [15]. Cold bonded fly ash aggregate produced by blending with 12–15% ground granulated blast furnace slag and rice husk ash showed higher strength properties of aggregate [16]. Sintered fly ash lightweight aggregate produced by heat and polymer treatment improve their strength, lower water absorption and pozzolanic activity. Accordingly the properties of aggregates differ in their micro-structural formation. In the case of sintered fly ash aggregate at higher temperature (1200–1300 °C) the SEM analysis showed reduction in pore area [17]. The closer bonding of particles in sintered aggregates resulted in higher strength [18] and further reduction in the thickness of ITZ around the dry aggregate [19,20]. The summary on various research studies indicated various aspects of producing high strength fly ash aggregates. In addition the composite performance depends on strength of aggregate and careful concrete mix design procedure.

1.1. Research significance

This paper reports a detailed investigation on the various mechanical and durability properties of fly ash aggregate substituted concretes. Physical and mechanical characterisation of cold bonded and sintered aggregates were studied systematically. Simplified concrete mix design procedure using light weight fly ash aggregates was proposed in this study. Further, the influence of binder (bentonite) and alkali (sodium hydroxide) addition on the strength properties of fly ash aggregates were evaluated in this study. Effect of accelerated curing procedures on the strength gain properties of various fly ash lightweight aggregate concrete was also investigated. Finally, the residual strength characteristics of various fly ash incorporated concretes were evaluated after subjecting to various durability tests.

2. Materials used

The materials used in this investigation consisted of class-F fly ash, bentonite, cement, fine aggregates and super plasticizer. The physical properties and chemical composition of the various raw materials used in the aggregate and concrete production are provided in Table 1.

2.1. Production of fly ash-bentonite aggregate

Fly ash aggregates were produced in a disc type pelletizer machine using agglomeration technique. Agglomeration is a process of producing artificial aggregate pellets without any external force due to rotational movement or tumbling force produced during pelletization process. Fly ash aggregates was produced using a specially fabricated disc type pelletizer machine shown in Fig. 1. The pelletizer disc consisted of 500 mm diameter with 270 mm depth and an adjustable disc which can be tilted from 30° to 40°. Based on trial studies, the angle of disc was set at 36° with an optimized speed of 55 RPM. The production involves the addition of dry materials in the disc and the calculated water being sprayed during the operation. Raw materials used in the production consisted of fly ash (80% of the total weight) and bentonite (20% of the weight). Initial trial studies were conducted to determine the optimum quantity of water, binder (bentonite) and alkali activator (sodium hydroxide at 10 M)). This was arrived based on the maximum pelletization efficiency and stability of fresh aggregates achieved during production leading to uniform spherical shaped pellets formed in 15 min duration. Further, the production of FAB aggregates was carried out with the calculated water content (25% of the weight of binder material) mixed with sodium hydroxide at 10 M and added into the pelletizer by means of spraying. The inclusion of binder in fly ash envisaged the early formation of pellets and the activator addition provided rapid hardening of fly ash balls without collapse. This provided a more stable formation of fly ash pellets. Initially the fly ash and bentonite powder were mixed properly in the disc pelletizer and then 25% of water content (with alkali activator) is sprayed during the processing. When the fly ash particles gain moisture it results in the small seed formation and the size of pellets increases with the duration. The disc pelletizer was run up to 15 min duration, based on the improved seed formation at optimized time duration and the cold bonded aggregates produced are shown in Fig. 2. After production, the pellets were air dried and followed by curing in hot air oven at 100 °C up to 7 days. The production of sintered fly ash aggregate was carried out in a muffle furnace by heating the cold bonded aggregates up to 950 °C. The snapshot of the muffle furnace and sintered aggregates is shown in Figs. 3 and 4.

2.2. Testing of aggregates

Mechanical properties of manufactured lightweight aggregates were evaluated from the crushing strength of the individual pellet and impact strength of the aggregates. Individual crushing strength of the spherical aggregates was tested using California bearing ratio (CBR) testing apparatus as shown in Fig. 5. A total of 30 numbers of pellets were selected in various size ranges from 6 mm to 12 mm and tested in CBR for evaluating the maximum failure load of aggregate. The impact test of the lightweight aggregate was conducted (shown in Fig. 6) as per the standard procedure given in IS: 2386-1963 (part IV) [21]. Aggregate samples consisting of particle size passing through 12.5 mm sieve size and retained on 10 mm sieve size

Table 1
Physical properties and chemical composition of various materials.

Observation	Fly ash–class F	Cement	Bentonite
Specific gravity	2.1	3.13	2.64
Blaine's fineness (m^2/kg)	400	325	–
SiO_2	56.2	18.5	47.84
Al_2O_3	25.8	5.24	14.85
Fe_2O_3	6.8	5.90	9.61
CaO	3.67	60.9	2.29
MgO	1.76	1.10	2.20
SO_3	0.47	1.50	–
Na_2O	2.06	–	2.88
K_2O	0.01	–	1.45
Cl^-	0.52	0.002	–
Loss on ignition	–	0.80	19.73