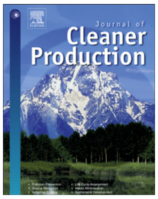
Journal of Cleaner Production xxx (2015) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

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



Use of Furnace Bottom Ash for producing lightweight aggregate concrete with thermal insulation properties

Binyu Zhang, Chi Sun Poon*

Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

A R T I C L E I N F O

Article history:
Received 18 June 2014
Received in revised form
29 December 2014
Accepted 2 March 2015
Available online xxx

Keywords:
Concrete
Lightweight aggregate
Furnace Bottom Ash
Thermal insulation

A B S T R A C T

The influence brought by Furnace Bottom Ash (FBA) incorporation on the properties of lightweight aggregate concrete was studied systematically. In total, six mixtures of concrete targeted at a 28 d compressive strength of 30 MPa were designed, including one control mix made with all normal weight aggregates and at a water/cement ratio (w/c) of 0.6, and another five lightweight aggregate concrete mixes at a w/c of 0.39 by using 0, 25%, 50%, 75% and 100% FBA replacing natural fine aggregate (crushed fine stone). The testing results of the hardened concrete properties showed that, for the lightweight aggregate concrete using 100% FBA to replace crushed fine stone, a 28 d oven-dried density of about 1500 kg/m^3 was obtained. The test results showed the lightweight aggregate concrete had lower strength and stiffness compared to the normal aggregate concrete. But in terms of the effectiveness of strength provided by unit weight of concrete indicated by compressive strength in MPa divided by saturated-surface dried (SSD) density in g/cm^3, f_c/D, a satisfactory ratio can be obtained when not more than 50% FBA was used to replace the crushed fine stone. The durability property indicated by the chloride ion penetration test shows the lightweight aggregate concrete with FBA had high chloride ion penetrability. The heat insulation property (thermal conductivity K-value) test demonstrated that by using the porous lightweight aggregate, the thermal conductivity could be lowered to around 70% of the control. When more FBA was used to replace crushed fine stone, the thermal conductivity value could be further reduced. The results of this study demonstrated it is feasible to produce lightweight aggregate concrete with high volume of FBA incorporation for building insulation uses.

1. Introduction

Recycling and reusing of waste materials has become an increasingly important research area in recent years, and it is widely recognized as an effective method for promoting sustainability. Zaman (2014) conducted a case study using the "zero waste index", and suggested that strategies should be taken to recycle waste to replace virgin materials to help improving sustainability. Blengini and Garbarino (2010) carried out a research on construction & demolition (C&D) waste recycling by adopting the life cycle analysis (LCA) method, and they suggested that recycle and reuse of C&D waste can alleviate pressure on landfill shortage while reducing natural resources consumption. Using of recycled materials in concrete is not always associated with inferior properties compared to concrete produced only with natural materials. A case study on preparing concrete for airport pavements using blasted furnace slag (BFS). Jamshidi et al. (2014) indicated that the use of recycled materials (BFS) not only benefits sustainable development from the aspect of waste reduction, but also the properties of concrete (e.g. structural performance) can be improved.

A large amount of FBA is generated as a by-product of coal fired power generation every day, and finding recycling outlets for FBA would contribute to the sustainable use of resources (Kou et al., 2012). Previous studies showed that FBA can be used as a lightweight material to replace natural aggregates for concrete production. Kou and Poon (2009) showed that for the concrete mix prepared with 100% FBA replacing natural fine aggregate, a compressive strength of 32 MPa was achieved after 28 d curing at a W/C ratio of 0.53. The 28 d compressive strength could be further improved to 65 MPa when the W/C was decreased to 0.34. Wongkeo et al. (2012) demonstrated the feasibility of using a ground bottom ash (BA) with similar chemical compositions to FBA to partially replace cement, and the result showed that 28 d compressive strength slightly increased from 9 MPa to 11 MPa with

---

* Corresponding author. Tel.: +852 27666024.
E-mail address: cecspoon@polyu.edu.hk (C.S. Poon).

http://dx.doi.org/10.1016/j.jclepro.2015.03.007

Please cite this article in press as: Zhang, B., Poon, C.S., Use of Furnace Bottom Ash for producing lightweight aggregate concrete with thermal insulation properties, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.03.007

the increase of BA replacement ratio from 0 to 30% at a fixed w/c ratio.

Energy saving is also an important issue in sustainability. According to the Hong Kong Electrical and Mechanical Services Department's (ESMD) 2013 annual report of energy end use break down, in the year 2011 space air conditioning accounted for about 23% and 26% of total annual electricity consumption in residential buildings and commercial buildings, respectively (Electrical and Mechanical Services Department, 2013), which indicates that building materials with better thermal insulation properties have a promising future. Previous research works proved that by using lightweight aggregate (expanded perlite) in concrete mixes, the thermal conductivity can be lowered to about 0.13 W/mK (Sengul et al., 2011). Demirboga and Kan (2012) prepared lightweight aggregate concrete with a modified waste expanded polystyrene (MEPS) to replace natural aggregates, the thermal conductivity of the concrete was reduced to 0.600 W/mK. Akçaözoglu et al. (2013) used recycled waste PET lightweight aggregate (WPLA) to produce concrete with improved thermal insulation property, and the result indicated that by replacing natural aggregate with WPLW at 60% by volume, the fresh concrete density was reduced gradually to 1530 kg/m^3 compared with 2240 kg/m^3 of the control mix, while the thermal conductivity value was reduced from 0.9353 W/mK to 0.3924 W/mK. Another commonly used aggregate to improve concrete insulation properties is rubber aggregate. Mohammed et al. (2012) prepared hollow concrete blocks of dimension 390 mm × 190 mm × 190 mm with 10%–50% crumb rubber incorporation, and the thermal insulation properties tests indicated that 50% rubber aggregate incorporation resulted in a reduction of concrete thermal conductivity from around 1.0 W/mK to nearly 0.6 W/mK. However, they also pointed out that the use of high volume rubber aggregate resulted in significant strength losses, as the concrete compressive strength was reduced from more than 12 MPa to less than 2 MPa due to the rubber aggregate incorporation.

As regards the mechanical properties of lightweight aggregate concrete, according to Akçaözoğlu, when the replacement ratio of normal weight aggregate by WPLA aggregate was increased to 60%, the compressive strength of the concrete using a 500 kg/m^3 cement content was only 9.5 MPa after 28 d curing and 11.1 MPa after 90 d curing, which indicated that the ratio of compressive strength in MPa divided by the saturated-surface dried (SSD) density (f_c/D) of this type of lightweight aggregate concrete was only around 6.0 to 7.0 (Akçaözoğlu et al., 2013). Ben Fraj et al. (2010) prepared lightweight aggregate concrete with a polyurethane foam waste (density 21 kg/m^3, water absorption 13.9% by volume), the results showed that at a w/c ratio of 0.55, the normal aggregate concrete attained a compressive strength of 38 MPa after 28 d curing while lightweight aggregate concrete only gained 16.5 MPa (when all the normal coarse aggregate was replaced by the polyurethane foam waste), and the f_c/D ratio was only 10.7. Strength loss due to lightweight aggregate incorporation limited the application of lightweight aggregate concrete in building construction.

But high strength lightweight aggregate concrete for structural uses had been prepared (Samuel et al., August 2011) by using a vacuum saturated pumice to serve as both the fine and coarse aggregates, with the w/c controlled between 0.21 and 0.25. The results showed that this type of lightweight aggregate concrete was able to achieve a 28 d compressive strength between 36.5 MPa and 40.5 MPa, while the f_c/D ratio tested at 28 d curing age was ranged from 18.1 to 19.6. Kockal and Ozturan (2011) investigated the mechanical properties of structural lightweight aggregate concrete by using two different types of sintered lightweight fly ash aggregates and one type of cold-bonded lightweight fly ash aggregate, the results showed that adding 10% silica fume by cement weight was effective in improving the mechanical and durability properties of the concrete. Oil palm shell (OPS) is another lightweight aggregate (density 1190 kg/m^3, 24 h water absorption 21.82%) that can replace natural coarse aggregate for the production of lightweight aggregate concrete, and it was demonstrated that when the cement content was controlled at 550 kg/m^3 and the w/c at 0.425, the f_c/D ratio from 22.1 to 24.3 was achieved at 28 days curing age (Shafigh et al., 2011).

Permeability is an important index in determining the durability properties of lightweight aggregate concrete. Liu et al. (2010) conducted a study on assessing the chloride ion penetration of lightweight aggregate concrete made with different types of expanded clay. The results indicated that concrete containing lightweight aggregate showed higher chloride ion penetrability than normal aggregate concrete, Silica fume was also found effective to mitigate the durability properties of lightweight aggregate concrete (Liu et al., 2010).

Other than hardened properties, the fresh concrete properties of lightweight aggregate concrete had also been investigated. Shafigh et al. prepared lightweight aggregate concrete with waste materials from palm oil industry (Shafigh et al., 2014), and the results indicated that the oil-palm-boiler clinker (OPBC) incorporation led to a reduction in slump value, Recycled clay had also been used as lightweight aggregate in concrete, and past study results showed that at a cement content 350 kg/m^3 and a w/c 0.55, the slump value of concrete mixtures containing recycled clay aggregate can be controlled to 120 mm–130 mm (Bogas et al., 2014).

But limited research has been done on assessing the thermal insulation property of lightweight aggregate concrete produced with FBA incorporation. This study is aimed to assess the feasibility of producing such type of lightweight aggregate concrete with satisfactory mechanical, durability and insulation properties.

2. Materials and methods

2.1. Materials

An ordinary Portland cement (ASTM Type I) sourced locally was used in this study, the density of which was 3.16 g/cm^3 and the specific surface areas was 3500 cm^2/g. The detailed chemical compositions of the cement are presented in Table 1.

Crushed granite with maximum sizes of 10 mm and 20 mm were used as natural coarse aggregate in the natural aggregate concrete, and a crushed fine stone with a fineness modulus of 3.5 was used as the fine aggregate for both the normal weight aggregate concrete and the lightweight aggregate concrete. The properties of the normal weight aggregates are listed in Table 2.

A Lightweight expanded clay aggregate (LECA) with a diameter ranged from 6 mm to 10 mm was used as the lightweight coarse aggregate in this study. The surface saturated dried density of the lightweight aggregate was 1192 kg/m^3, and the 24 h water absorption value was 9.41%, as listed in Table 2.

The FBA used in this study was sourced from a local power generation plant. FBA is a by-product of coal fired power generation plants, and its density and water absorption values vary with different sources of coal and type of plants. FBA used in this series of experiment had a saturated surface dried density of 2208 kg/m^3, 24 h water absorption of 11.17%, and a fineness modulus of 3.3. The chemical compositions of the FBA are presented in Table 1, and the properties of FBA can be found in Table 2.

A superplasticizer ADVA 109 (Grace) was used to control the workability, as indicated by the slump values of the fresh concrete mixtures. The amount of superplasticizer used in each mix proportion is listed in Table 3.

Please cite this article in press as: Zhang, B., Poon, C.S., Use of Furnace Bottom Ash for producing lightweight aggregate concrete with thermal insulation properties, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.03.007