Construction and Building Materials 151 (2017) 441–448

Contents lists available at ScienceDirect

Construction and Building Materials

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

Utilizing high volumes quarry wastes in the production of lightweight foamed concrete

Siong Kang Lim[a], Cher Siang Tan[b], Bo Li[c,*], Tung-Chai Ling[d,*], Md. Uzzal Hossain[e], Chi Sun Poon[e]

[a] *Faculty of Engineering & Science, Universiti Tunku Abdul Rahman, Kuala Lumpur, Malaysia*
[b] *Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia*
[c] *Department of Civil Engineering, The University of Nottingham Ningbo China, 199 Taikang East Road, Ningbo 315100, China*
[d] *College of Civil Engineering, Hunan University, Changsha, Hunan, China*
[e] *Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hong Kong*

HIGHLIGHTS

- High volume quarry dust is utilized in producing lightweight foamed concrete (LFC).
- Fluidity, strength, thermal conductivity and sustainability of LFC are examined.
- The fluidity of LFC is decreased as the incorporation of high volume quarry dust.
- The strength and thermal conductivity are increased for LFC with quarry dust.
- LFC containing quarry dust consumes less energy and emits less greenhouse gases.

ARTICLE INFO

Article history:
Received 22 December 2016
Received in revised form 5 June 2017
Accepted 15 June 2017

Keywords:
Lightweight foamed concrete
Thermal conductivity
Fluidity
Compressive strength
Quarry dust
Life cycle assessment

ABSTRACT

Quarry dust, a by-product of stone grinding, cutting, sieving and crushing, is abundantly available and can create many on-site and off-site environmental problems. This paper investigates the feasible utilization of quarry dust as an alternative to river sand in the production of lightweight foamed concrete (LFC). LFC with a density of 1300 ± 50 kg/m^3 and fixed cement/filler ratio of 1:1 were adopted in this study. Quarry dust was used to replace sand at ratios of 75% and 100%, and four different water-to-cement ratios (w/c) of 0.52, 0.54, 0.56 and 0.58 were studied and compared. For a given w/c ratio, it was found that the use of high volume quarry dust could reduce the fluidity and increase the compressive strength and the thermal conductivity of LFC. However, no significant decrease of compressive strength was observed with the increase of w/c ratio, probably due to the reduction of foam volume requirement in the system. Life cycle assessment results indicated that the LFC containing quarry dust possessed less environmental impact in terms of lower energy consumption and lesser amount of greenhouse gases emission.

1. Introduction

Foamed concrete is classified as lightweight concrete with cellular structure, in which air voids are created in paste or mortar by a proper foaming agent. It is normally produced by mixing a cement paste or mortar, with a separately manufactured foaming agent and possesses high flowability, low density and outstanding thermal insulation properties. With proper control of the foaming agent dosage, a wide range of densities (e.g. from 400 to 1600 kg/m^3) of lightweight foamed concrete (LFC) can be produced for various construction applications, such as structural elements, partition boards, insulation, filling grades, etc. [1,2]. Jones and McCarthy [3] developed a foamed concrete with the incorporation of fly ash, which exhibited satisfactory loading behaviour for structural applications. Proper cement/filler ratio, air content, and water-to-cement ratio in LFC are essential parameters to gain good mechanical strength, desired density and good workability as well as lowering the cost [4].

Sand is the typical aggregate used in concrete production. River sand composed mainly of silica (silicon dioxide, SiO_2), normally has a homogeneous granular shape and consistency in its surface appearance. A shortage of natural river sand has stimulated research to find new materials as a replacement. Many alternative materials have been investigated and proposed to replace river sands in cement mortars or concrete. Ling and Poon [5] investigated the feasible use of recycled beverage and cathode ray tube

---

* Corresponding authors.
E-mail addresses: bo.li@nottingham.edu.cn (B. Li), tcling611@yahoo.com (T.-C. Ling).

http://dx.doi.org/10.1016/j.conbuildmat.2017.06.091

(CRT) funnel glass as alternative to fine aggregates in mortar. It was demonstrated that mortars prepared by both types of recycled glass were comparable to mortar containing 100% sand. Zhao et al. [6] further validated the utilization of recycled CRT funnel glass for the preparation of high-density concrete. Al-Tayeb et al. [7] investigated the effect of replacement levels of sand by fine crumb rubbers on the behaviour of composite beams. It was found that the impact bending load of beam could be enhanced by the incorporation of crumb rubber. Singh and Siddique [8] found that the concrete incorporating coal bottom ashes as fine aggregates exhibited comparable behaviour to that of control concrete in terms of compressive strength, water absorption and abrasion resistance. Singh et al. [9] conducted a comprehensive review on the use of granite dust as a replacement of river sand for producing sustainable concrete. Granite dust concrete exhibited a denser microstructure and compacted matrix at the optimum replacement ratio of river sand, which in turn enhanced the mechanical and durability properties. On the environmental aspect, by utilization of waste materials in concrete, it could alleviate the burden of waste disposal and conserve the already depleted river sand resources.

Alternatively, quarry dust produced (about 10–15%) from the extraction process of rock at quarries could be used to replace sand for the production of concrete. Although quarry dust did not possess similar granular shapes as river sand, the other physical and chemical compositions of quarry dust seem to be comparable to river sand [10]. It has been demonstrated that replacing sand with quarry dust was applicable for the production of self-compacting concrete (SCC), high-strength concrete and bricks.

Ho et al. [11] investigated the feasibility of replacing limestone powder by quarry dust powder in SCC. It demonstrated that incorporating quarry dust in SCC requires a higher superplasticizer dosage to achieve similar workability. Dehwah [12] investigated the mechanical properties of SCC produced with quarry dust, silica fume plus quarry dust, or fly ash only. It was found that SCC incorporating 8–10% quarry dust possessed the similar mechanical properties as that of SCC prepared by using quarry dust plus silica fume or fly ash only. Galetakis et al. [13] investigated the utilization of quarry dust in self-flowing castable building elements. It was proven that the mix formulation with quarry dust was reliable and practical to cast load-bearing and decorative building elements. Raman et al. [14] replaced 10–40% of sand with quarry fines in the production of high-strength rice husk ash (RHA) concrete, and asserted that quarry dust could be used as a viable alternative to sand. In the case of bricks, Shakir et al. [15] found that the compressive strength of bricks increased as the content of quarry dust increased. A similar finding was also reported for normal weight concrete [16]. In addition, full replacement of sand with quarry dust in concrete was possible when proper treatment was applied before its utilization [10]. The compressive and flexural strengths of 100% quarry dust concrete were 10% higher than concrete without quarry dust (only river sand). Thomas and Harilal [17] investigated the mechanical properties of quarry dust aggregate concrete subjected to elevated temperature. Specially, quarry dust was first agglomerated into aggregates through a cold bonding process with the incorporation of fly ash.

Quarry fines have also been used as recycled material in the production of LFC [18]. Jones et al. [18] found that 1000 kg/m^3 plastic foamed concrete with coarser quarry dust exhibited a higher flow value as compared to the corresponding foamed concrete prepared with very fine sand. However, the results were inverted when the density of foamed concrete reached 1400 kg/m^3 under the same conditions. The coarser quarry dust used in LFC resulted in a lower compressive strength regardless of its density. Although studies have been conducted on the utilization of coarse quarry dust in LFC, there is limited information reported on the use of refined quarry dust in LFC, especially at a higher replacement volume. Also, the effect of incorporating high-volumes of quarry dust on the thermal properties of LFC remains uncertain. This paper aims to investigate the influence of high-volume (75% and 100%) refined quarry dust as a substitute to river sand in the production of LFC. Fresh and hardened properties as well as the thermal conductivity of LFC were studied. The effects of different water-to-cement ratios were also studied. Moreover, life cycle assessment (LCA) of LFC with different contents of refined quarry dust was compared and discussed.

2. Experimental programme

2.1. Materials

In this study, the hardened density of all the LFC was designed at 1300 ± 50 kg/m^3. The materials used were ordinary Portland cement (OPC), refined quarry dust, river sand, tap water and foaming agent. Type I OPC was used according to ASTM C150 [19] and MS 522: Part 1 [20]. The chemical compositions of OPC and its physical properties are tabulated in Table 1. The refined quarry dust and river sand were obtained through a sieving process in which both passing through a sieve size of 600 μm. The particle size of river sand and quarry dust are shown in Fig. 1. The maximum sizes of river sand and quarry dust were less than 600 μm with a fineness modulus of 1.30 and 1.04, respectively. The primary sizes ranged from 150 to 300 μm with a specific gravity of 2.60. The fineness of both fillers exceeded the upper boundary limit of zone 4 fine sand in accordance with BS 882 [21]. The particle shape for river sand was rounded and angular, with a granular surface texture, whereas the refined quarry dust was flaky in shape and rough in surface texture. The typical chemical composition of quarry dust and river sand can refer to Ilangovanan et al. [10]. A synthetic foaming agent with a specific gravity of 1.03 was adopted throughout the experiment.

2.2. Mix proportions

Lightweight foamed concrete was prepared based on a fixed binder/filler ratio of 1.0. Stable foaming agent with a density of 45 g/L was produced by using the dry preformed foaming method [4,22,23]. The foaming agent was diluted with water at a volumetric ratio of 1:30. Three series of mixtures were prepared, namely (i) 100% refined river sand, (ii) 25% refined river sand plus 75% refined quarry dust, and (iii) 100% refined quarry dust. In order to obtain an average 28-day compressive strength of 4.14 MPa, as per the requirement of ASTM C129 [24], the water-to-cement ratios of 0.52, 0.54, 0.56 and 0.58 were tested. The mix formulations are summarized in Table 2.

2.3. Specimens preparation

Two types of specimens were prepared for measuring compressive strength and thermal conductivity, including 100 × 100 × 100 mm cube and 300 × 300 × 100 mm panel. The specimens were de-moulded after 24-h curing. All the samples were water cured at the temperature of 25 ± 3 °C.

Table 1
Chemical compositions and physical properties of OPC.

	OPC
Chemical Composition	
Silicon dioxide (SiO_2) (%)	21.1
Aluminium oxide (Al_2O_3) (%)	5.2
Ferric oxide (Fe_2O_3) (%)	3.1
Calcium oxide (CaO) (%)	64.4
Magnesium oxide (MgO) (%)	1.1
Sulphur oxide (SO_3) (%)	2.5
Sodium oxide (Na_2O) (%)	0.2
Potassium oxide (K_2O) (%)	0.6
Titanium oxide (TiO_2) (%)	0.2
Phosphorous oxide (P_2O_2) (%)	<0.9
Carbon content (C) (%)	–
Physical Properties	
Loss on ignition (LOI)	2.4
Specific gravity	3.15
Fineness in Blaine (cm^2/g)	3170
Fineness (% passing 45 μm)	93.0
Mechanical Properties	
Compressive strength at 28 days (MPa)	48.9