Construction and Building Materials 167 (2018) 791–812

Contents lists available at ScienceDirect

Construction and Building Materials

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

Development of lightweight strain hardening cementitious composite for structural retrofit and energy efficiency improvement of unreinforced masonry housings

Honggang Zhu[a], Kai Tai Wan[b,*], Elnara Satekenova[c], Dichuan Zhang[c], Christopher K.Y. Leung[d], Jong Kim[c]

[a] Nano and Advanced Materials Institute Limited, Hong Kong
[b] Department of Civil and Environmental Engineering, Brunel University London, UK
[c] Department of Civil Engineering, Nazarbayev University, Kazakhstan
[d] Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong

HIGHLIGHTS

- Lightweight strain hardening cementitious composites (LSHCC) is developed.
- The developed LSHCC can improve the energy efficiency of building.
- Innovative survivability test for hollow micro glass bubble is introduced.
- Tensile, thermal and durability properties of LSHCC is reported.
- The use of LSHCC for strengthening of unreinforced masonry wall is demonstrated.

ARTICLE INFO

Article history:
Received 5 December 2017
Received in revised form 5 February 2018
Accepted 6 February 2018

Keywords:
Lightweight strain hardening cementitious composites
Hollow micro glass bubble
Tensile ductility
Thermal conductivity
Pushover analysis
Smeared crack material model

ABSTRACT

The thermal, mechanical and durability properties of lightweight strain hardening cementitious composite (LSHCC) as well as the effectiveness of using LSHCC for structural retrofitting of unreinforced masonry (URM) wall is reported in this study. The proper range of water content, dosage of superplasticiser and viscosity modifying agent was explored from the survivability test of glass micro hollow bubble (3M-S15), which was much more fragile but effective in reducing the thermal conductivity of the composite than other studies. Then, the tensile properties of LSHCC with plastic-state density of about 1300–1400 kg/m^3 from different proportion of replacement of ordinary Portland cement (OPC) by fly ash (FA) and ground granulated blast-furnace slag (GGBS) as well as different volume fraction of polyvinyl alcohol (PVA) fibre were measured. The tensile ductility of LSHCC of replacement by FA was in general better than pure OPC or with GGBS blends. The tensile strength and ductility of LSHCC with 1.75% volume fraction of PVA fibre was about 3 MPa and 2–4%, respectively. The compressive strength ranged from 14 to 31 MPa. The thermal conductivity of selected LSHCC ranged from 0.34 to 0.51 W/m·K. The coefficient of water permeability of LSHCC was comparable with reference normal concrete and the engineered cementitious composite (ECC-M45) in the literature. The coefficient of chloride diffusivity of most LSHCC in this study was lower than the reference concrete because of the chloride binding of FA and GGBS. However, the carbonation rate of the LSHCC was generally higher. Three sets of LSHCC with similar tensile strength but different ductility were chosen for the evaluation of the effectiveness on structural retrofitting of an unreinforced masonry wall by in-plane and out-of-plane pushover analysis. The parameters of a finite element model with smeared crack material model was tuned based on the stress-strain relationship of LSHCC measured from the tensile tests in this study. There was no improvement of using LSHCC with 0.6% tensile ductility. By applying a 10 mm thick LSHCC with 2.2% and 4.4% tensile ductility on each side of an URM wall, the ductility of the retrofitted wall under in-plane loading was increased by 38% and 72%, respectively while it was increased by 164% for both kinds of LSHCCs for out-of-plane loading.

---

* Corresponding author.
E-mail address: KaiTai.Wan@brunel.ac.uk (K.T. Wan).

https://doi.org/10.1016/j.conbuildmat.2018.02.033
0950-0618/

Table 1
Summary of raw materials, density, thermal conductivity of lightweight strain hardening composite.

	3 M-S38	3 M-S60	EG	MS
Matrix	OPC	OPC	FAG	FAG
LWA-matrix wt%	20	50	16	10
Density (kg/m^3)	1,450	930	1,754	1,586
Thermal conductivity (W/m·K)	N/A	N/A	~0.9	~1.1
Ultimate tensile strength (MPa)	4.31	2.85	3.8	3.4
Tensile ductility (%)	4.24	3.70	3.7	3.5

EG: expanded recycled glass.
MS: microscopic hollow ceramic spheres.
LWA: lightweight aggregates.
FAG: fly ash based geopolymer.

Table 2
Properties of lightweight aggregates.

	unit	S15	S38*	S60*	EG#	MS#
Typical true specific gravity		0.15	0.38	0.6	1.4	0.85
Thermal conductivity	(W/m·K)	0.055	0.127	0.200	N/A	0.1
Particle size range	(μm)	25–90	15–75	15–55	40–125	38–125
Median particle size	(μm)	55	40	30	N/A	N/A
Isostatic crush strength	(MPa)	2.1	27.6	68.9	N/A	45

is the expanded recycled glass and microscopic hollow ceramic spheres used in [43].
* Is the glass micro-hollow bubble used in [32].

Table 3
XRF results and loss of ignition (LOI) of the raw materials of the cementitious matrix (in weight %).

	OPC	FA	GGBS
SiO_2	19.4	52.0	32.2
CaO	67.0	4.7	46.5
Al_2O_3	3.4	30.7	12.3
Fe_2O_3	3.5	5.9	1.0
SO_4	5.1	1.5	3.1
MgO	1.0	1.6	4.1
TiO_2	0.2	2.3	0.6
MnO	0.2	0.1	0.2
K_2O	0.2	1.2	–
LOI	–	3.1	–

1. Introduction

Unreinforced masonry (URM) housings are vulnerable to lateral loadings such as seismic action [29,23,11] and wind pressure [17]. Although it is prohibited or strictly controlled to build new URM housings in many seismic regions, it is necessary to preserve the surviving/existing URM housing stock, especially some of which are historic. Confined masonry (CM) wall as an infill of reinforced concrete frame is common in low to medium height residential buildings. It can provide in-plane ductility under seismic [12,27], however, out-of-plane collapse is still critical for old existing buildings, which were not in accordance with proper dimensioning and detailing required in modern seismic design codes [24,55]. The collapse of confined masonry wall makes the housings no longer serviceable and may cause serious damage to adjacent structures.

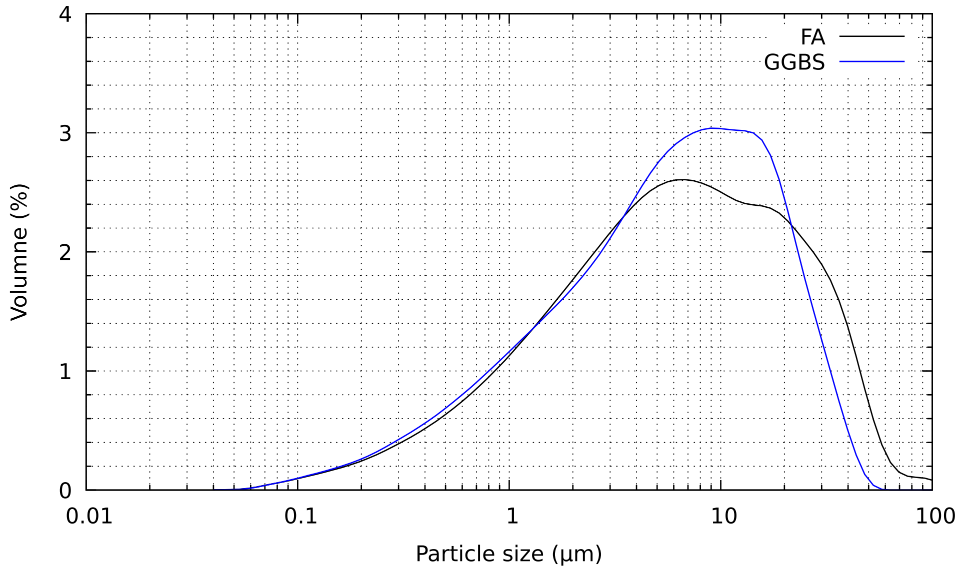

Fig. 1. Particle size distribution of fly ash (FA) and ground granulated blast-furnace slag (GGBS) in this study.