Composites: Part B 51 (2013) 68–78

Contents lists available at SciVerse ScienceDirect

Composites: Part B

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

The structural behaviour of HCWA ferrocement–reinforced concrete composite slabs

Chee Ban Cheah *, Mahyuddin Ramli

School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Penang, Malaysia

ARTICLE INFO

Article history:
Received 25 February 2012
Received in revised form 30 October 2012
Accepted 24 February 2013
Available online 13 March 2013

Keywords:
A. Hybrid
A. Particle-reinforcement
A. Recycling
B. Mechanical properties
C. Analytical modelling

ABSTRACT

This study was performed with the aim to assess the structural behaviour of ferrocement–reinforced concrete composite slab system with high calcium wood ash (HCWA) high strength mortar used as the compression zone. The proposed slab system consisted of conventional reinforced concrete slab topped with a layer of high strength ferrocement composite containing various contents of HCWA by total weight of binder. A total of six numbers of one-way composite slab prototypes were subjected to four point flexural load test to ultimate failure. The main parameters of the study include serviceability moment, ultimate moment capacity, flexural stiffness in serviceability and post cracked conditions, crack width development, crack spacing and failure mode. Results of the investigation indicate a significant enhancement in the first crack load and ultimate failure load of the composite slab system with the use of HCWA in the mortar layer at cement replacement level of 2% to 8% by binder weight. In addition, the inclusion of HCWA at various replacement levels also contributed to a reduction in the magnitude of average crack width at a given flexural load.

1. Introduction

Several recent research studies had established that high calcium wood ash (HCWA) can be used as mineral admixture for production of high strength mortar and ferrocement composite. In recent studies [1–4], wood ash with very high calcium oxide mineral content had been thoroughly characterised and incorporated as a constituent binder material in the production of high strength mortar. The studies concluded that the use of high calcium wood ash as a partial cement replacement material at replacement level up to 6% by total weight of binder had resulted in a significant improvement in mechanical strength and durability performance of mortar produced. It was justified that the use of high calcium wood ash which has high Portlandite content in conjunction with densified silica fume which is rich in amorphous silica content triggers a rigorous pozzolanic reaction between the two substances. The reaction resulted in the formation of greater amount of secondary calcium silicate hydrate and refinement in pore structure of resultant cementitious composites [2,3]. Hence, a dense mortar with high compressive strength, flexure strength and durability performance which is suitable for use as mortar matrix in high performance ferrocement composite was formulated.

Ferrocement is a thin reinforced concrete composite typically consists of cement mortar reinforced with closely spaced layers of continuous small diameter wire mesh closely binded together to create a stiff structural form. The materials for the reinforcing mesh used are normally steel, synthetic woven fibres or fibre reinforced polymers [5]. As compared to the conventional reinforced concrete, ferrocement is reinforced in two directions. Hence, there is a tendency for ferrocement composites to have homogeneous isotropic properties in both longitudinal and transversal directions. With that, ferrocement composites usually exhibit high tensile strength, high modulus of rupture and excellent bonding interaction between embedded internal mesh reinforcements and surrounding cement mortar matrix [6]. Besides, ferrocement composite also possesses high degree of elasticity and resistance to cracking. These attributes have resulted in the successful application of ferrocement composites in the fabrication of ship's hull, building construction (low cost housing), rehabilitation of existing structures and fabrication of floating marine structures and sewerage pipelines [5,7].

In the current development of ferrocement applications, several studies [8–14] have been performed to study the structural performance of ferrocement–reinforced concrete composite structural elements. Al-Kubaisy and Jumaat [14] studied the flexure behaviour of reinforced concrete slab with ferrocement tension zone cover. In the study, it was concluded that composite slab with ferrocement tension zone cover exhibited superior flexure stiffness, crack development behaviour and higher first crack moment

* Corresponding author. Present address: School of Housing, Building and Planning, Universiti Sains Malaysia, 11800 Penang, Malaysia. Tel.: +60 0164846502; fax: +60 046576523.

E-mail address: ccb09_hbp2@student.usm.my (C.B. Cheah).

1359-8368/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.compositesb.2013.02.042

as compared to an equivalent conventional reinforced concrete slab. In another related study [11], the shear transfer mechanism within a ferrocement–reinforced concrete composite beam was investigated. The study focused on the transfer of shear stress between the ferrocement layer and the reinforced concrete beam upon being subjected to flexural load condition. The placement of shear studs to bridge the ferrocement layer and the reinforced concrete beam was recommended in the study. This is to ensure a proper composite interaction between the ferrocement and the reinforced concrete beam. Thanoon et al. [9] proposed a novel ferrocement composite slab system with ferrocement tension zone and engineering clay bricks in the compression zone. The study focused on the method to ensure a proper composite interaction between the tension and compression layers which were separated by a cold joint. It was concluded that a cast in steel truss system which bridge the tension and compression layers is an effective interlocking mechanism for transferring the shear stresses which is developed between the ferrocement tension layer and the engineering clay bricks compressive layer. The steel truss system also solves the cold joint problem and prevents the longitudinal crack problem which normally occurs at the failure of composite structural element. Most of the past studies performed on the ferrocement–reinforced concrete composite flexural member focused on the use of ferrocement as the tension layer. However, the structural behaviour of ferrocement–reinforced concrete composite flexural member with high strength ferrocement compression zone has not been studied.

In this study, the structural performance of composite slabs with high strength ferrocement compression zone fabricated using high strength mortar with various HCWA contents was investigated. The engineering parameters considered in the study are flexure stiffness, serviceability load, ultimate load bearing capacity and crack development behaviour.

2. Experimental programme

A total of six simply supported one way spanning slabs were tested to ultimate failure. Dimensions of tested slab panels were 1200 × 600 × 100 mm. Steel area fraction of tension and compression reinforcements in the longitudinal directions was maintained constant at 0.295% and 0.339%, respectively for all test specimens. The top 30 mm of the slab thickness comprises of high strength mortar with mix composition shown in Table 1. The detailing of internal reinforcement, dimensions and specifications of test slabs are shown in Fig. 1.

3. Materials and methods

3.1. Materials

3.1.1. Hydraulic binder and aggregate

Locally available ASTM Type I Portland Cement (PC) was used as the major binder material. Densified silica fume (DSF) with amorphous silica content of 84.0% by total weight of the material was used in the study. High calcium wood ash (HCWA) used in the study possesses calcium oxide content of 61.0% and major mineral phases of calcium carbonate and Portlandite (CaOH). Detailed information on the characterisation method, chemical properties and physical properties of the aforementioned powder materials are presented in previous publications [2,3]. Locally sourced river sand with grading in compliance with overall grading limits prescribed by BS 882 [15] was used as aggregate for the mortar mixes. The river sand used was washed prior being used for mixing to remove natural silt and clay present in the raw stock pile. Crushed granite rocks with maximum aggregate size of 20 mm were used as coarse aggregate for the concrete mix.

3.1.2. Superplasticizer and mixing water

The high range water reducing agent used in the study was a polycarboxylic ether based superplasticizer with commercial name of Glenium Ace 388. Relative density of the superplasticizer used was 1.10 at 25 °C. Water from the potable water supply network was used as mixing water.

3.1.3. Normal strength concrete

Constituent materials of Grade 30 concrete specified in Fig. 1 consist of ASTM Type I Portland Cement, natural river sand and crushed granite aggregate in the mass ratio of 1:3:2.1 with water to binder ratio of 0.55. The concrete mix was designed to achieve a slump value of 50 mm in its fresh state and a target characteristic cube compressive strength of 30 MPa at the age of 28 days. The actual average 28 days compressive strength of 31.15 MPa was achieved by the hardened concrete.

3.1.4. Longitudinal high tensile steel bars and square wire mesh

The longitudinal tension reinforcements used in all slabs consisted of 9 numbers of 5 mm diameter high tensile steel bars with average yield strength of 493.1 MPa and tensile strength of 607.8 MPa. These properties are in compliance with the characteristics tensile properties of class B500C high tensile steel bars prescribed in BS 4449 [16]. Total elongation at maximum force was 7.5%. Elastic modulus of elasticity of the steel bars are taken as 205 GPa as specified in the BS5896 [17] for high tensile steel reinforcements.

As for the reinforcement configuration in the ferrocement composite zone, a total of 5 layers of woven galvanised steel square mesh with a wire diameter of 1.05 mm and 13 mm spacing were provided as an internal reinforcement for each of the ferrocement panel fabricated. The mesh was tested in the laboratory in accordance to the guide for the design, construction and repair of ferrocement reported by ACI committee 549 [18]. Yield strength of the wire mesh was determined to be 253.8 MPa. The average ultimate strength and elongation of the wire mesh was found to be 378.4 MPa and 8.09%, respectively. With reference to ASTM A36 [19] the elastic modulus of steel wire corresponding to the yield strength of 253.8 MPa was stated to be 200 GPa.

Table 1
Proportion of constituent materials of high strength mortar mixes and normal strength concrete.

Mix designation	% DSF	% HCWA	Cement (kg/m^3)	DSF (kg/m^3)	HCWA (kg/m^3)	Granite (kg/m^3)	Sand (kg/m^3)	Water (kg/m^3)	SP dosage (%)	Water/binder (ratio)	Mortar flow (%)	Slump (mm)
Grade 30 concrete	–	–	350	–	–	740	1050	193	0	0.55	–	50
CS	7.5	0	655	53	0	0	1593	227	1	0.32	30.2	60
W2	7.5	2	588	53	14	0	1593	227	1	0.32	41.4	50
W4	7.5	4	627	53	28	0	1593	227	1.1	0.32	26.4	50
W6	7.5	6	612	53	42	0	1593	227	1.3	0.32	26.6	65
W8	7.5	8	598	53	57	0	1593	227	1.4	0.32	26.9	85
W10	7.5	10	584	53	71	0	1593	227	1.5	0.32	30.9	50