Construction and Building Materials 36 (2012) 104–109

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Mix design methodology for laterized self compacting concrete and its behaviour at elevated temperature

George Mathew [a,*], Mathews M. Paul [b,1]

[a] Division of Safety and Fire Engineering, School of Engineering, Cochin University of Science and Technology, Kochi, Kerala, India
[b] Dept. of Civil Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala 686 666, India

HIGHLIGHTS

- ▶ A simple mix design procedure has been proposed for medium strength (M20–M40) Laterized Self Compacting Concrete (LSCC).
- ▶ Development of surface crack can be delayed up to 600 °C with LSCC.
- ▶ Explosive spalling can be prevented up to 800 °C when LSCC is used.
- ▶ LSCC could be considered as a substitute fire protection material for conventional concrete.

ARTICLE INFO

Article history:
Received 15 June 2011
Received in revised form 7 March 2012
Accepted 25 April 2012
Available online 15 June 2012

Keywords:
Laterized concrete
Self compacting concrete
Fly ash
High temperature concrete
Marginal material
Spalling
Mix design
Fire protection
Concrete

ABSTRACT

Marginal materials like laterite aggregate can be used in concrete when performance is more important than strength criteria. A mix design procedure for Laterized Self Compacting Concrete (LSCC) and its performance under elevated temperature has been presented. Test specimens were heated to 200 °C, 400 °C, and 600 °C. The properties of LSCC at fresh and hardened stages were observed. It could be concluded that the type of aggregate and fly ash content prevented the explosive spalling in LSCC even up to 800 °C and the development of surface crack was also delayed up to 600 °C. Further, LSCC could be considered as a substitute fire protection material for conventional concrete.

1. Introduction

Concrete is an extensively utilised material in construction such that its use is only next to the consumption of water. With fast depleting state of natural resources like river sand and aggregates, it is time to look for alternate materials for making concrete. In instances where the performance of concrete is more important than strength criteria, marginal materials are used for concrete making. Many locally available marginal materials can be used in concrete [1]. Because of its abundance in nature, laterite aggregate can be considered as one of the potential marginal materials to replace conventional aggregates in concrete. Laterized concrete is a concrete in which the aggregates are partially or fully replaced with laterite aggregate. Laterized concrete has been used for pavement construction, house construction, etc. in the past [2–4].

In places where compaction and placing are difficult, such as jacketing of structural elements for fire protection, and back filling near retaining structures, self compacting concrete (SCC) is a better choice than conventional concrete. In plastic state, SCC fills the form work under its own weight. The hardened concrete is dense, homogenous, has better engineering properties and is more durable than traditional vibrated concrete. Laterite aggregates can be collected either by quarrying from the laterite deposits or by collecting from weathered aggregates from the earth surface. The later has better physical properties [5,6] and can be used as all in aggregate for making concrete.

Even though limited study has been carried out in the area of laterized concrete [2–4,7–10], proper mix design methodology for LSCC is lacking at present. No study has been reported in the case of LSCC and about its performance under elevated temperature. This paper proposes a mix design methodology for LSCC using

* Corresponding author. Tel./fax: +91 4842577794, mobile: +91 9447726194.
E-mail addresses: george_m@cusat.ac.in (G. Mathew), mmp_mace@rediffmail.com (M.M. Paul).
1 Tel.: +91 4852571144, mobile: +91 9946151510.

0950-0618/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2012.04.057

weathered all in laterite aggregate and checks its suitability as a fire protection material.

2. Mix design methodology for LSCC

Self compatibility can be largely affected by the characteristics of materials and the mix proportion. A rational mix design method for SCC was initially proposed by Okumura and Ozawa [11]. Nan Su et al. [12] proposed a simplified method based on Okumura's method. Karjini and Anadinni [13] observed that the cement content calculated using Nan Su method was not sufficient for a uniform mix and has proposed a modified Nan Su method.

In the present investigation, the modified Nan Su method has been considered as a base.

Weathered laterite aggregates collected from different sources have been considered for the study. Trial mixes have been made for strength ranging from M20 to M40 using the materials collected. Based on the observations made such as filling ability, stability, and strength properties, a mix design methodology has been arrived for LSCC.

In general, the fly ash content in SCC ranges from 8% to 60% of the total powder content [14–16], and is one of the important ingredients in SCC to ensure proper flow characteristics. For the proposed mix design methodology of LSCC, the total powder content comes in the range from 670 kg to 810 kg with fly ash content varying from 50% to 46%.

2.1. Cement content

Based on trial mixes, it was observed that the modification factor proposed for the calculation of cement content by modified Nan Su method for SCC is not sufficient for LSCC. It has been reported elsewhere that SCC with marginal materials as aggregates requires more powder content to achieve uniform flow [1,17]. Accordingly, a different modification factor has been proposed for LSCC and the cement content can be calculated using the following relation.

$$C_w = M_f[f_{ck}/0.14] \tag{1}$$

where C_w is the weight of cement for 1 m^3 of concrete in kg, M_f the modification factor, and f_{ck} is the characteristic cube compressive strength of concrete in MPa.

The proposed modification factor for LSCC is given in the following equation:

$$M_f = 3.75 - f_{ck}/12 + f_{ck}^2/1400. \tag{2}$$

2.2. Fly ash additions

Commonly used addition in SCC to improve various properties like flowability, cohesion, segregation resistance, bleeding, settlement etc., is fly ash [18,19]. Because of less fine materials in laterite all in aggregate, large quantity of additional fine materials is required for making LSCC. Accordingly, the quantity of fly ash to be used in LSCC can be determined using the relation

$$F_w = F_f C_w[S_f/S_c] \tag{3}$$

where F_w is the weight of fly ash for 1 m^3 of concrete in kg, F_f the fly ash factor, S_f the specific gravity of fly ash, and S_c is the specific gravity of cement and

The fly ash factor can be calculated using the relation

$$F_f = 1.74 - [f_{ck}/100] \tag{4}$$

The F_f has been arrived at based on the fact that, quantity of fly ash required for LSCC is less for higher grades of concrete as higher grade of concrete has more cement content than lower grade.

2.3. Water powder ratio

The water content required for mixing is an important parameter in mix design and this is the total amount of water required for cement and filler. For f_{ck} ranging from 20 to 40 MPa, the water to powder ratio (*W*/*P*) may be calculated using the relation

$$(W/P) = 0.4 - [2.5/1000]f_{ck} \tag{5}$$

2.4. Aggregate content

Laterite all in aggregate of 12.5 mm down has been considered for the present study. It has been reported elsewhere that the air content in SCC ranges between 1% and 1.5% [12]. In LSCC, the air content can be taken as 1% of the total volume of concrete. Having obtained all other ingredients for LSCC, the aggregate content can be calculated based on the volume ratio equilibrium equation. Accordingly, the following equation can be used for the calculation of aggregate in one cubic meter of LSCC.

$$1000(1 - V_a) = [C_w/S_c] + [F_w/S_f] + [A_w/S_a] + W \tag{6}$$

where V_a is the air content in%, A_w the weight of laterite aggregate in kg, S_a the specific gravity of laterite aggregate, and *W* is the Weight of water in kg.

2.5. Superplasticiser (sp) dosage

Adding an optimum amount of SP will improve the flowability, self-compacting ability, segregation resistance of LSCC and will reduce water demand for meeting the design requirements. The water content in SP should be adjusted in the total quantity of mixing water.

3. Experimental investigation

The experimental investigation has been carried out for the confirmation of the mix design method suggested as well as to check the suitability of LSCC as a fire protection material. M25 grade concrete has been considered for the present study.

3.1. Materials

Ordinary Portland cement, ASTM class F fly ash [20] and weathered laterite all-in-aggregate of maximum size 12.5 mm have been used in the present investigation. Specific gravity of the fly ash used was 2.05. Poly-Carboxylic Ether based high performance super plasticizer at the rate of 1% of the total powder content was used for obtaining the required flow properties. The various properties of weathered laterite aggregate are presented in Tables 1 and 2.

3.2. Mix proportion

Table 3 presents the quantities of ingredients required for one cubic meter of M25 grade LSCC.

Table 1
Chemical properties of weathered laterite aggregate.

Properties	Value%
SiO_2	30.950
TiO_2	00.686
Al_2O_3	21.520
MnO	00.018
Fe_2O_3	35.800
CaO	00.123
MgO	Not detected
Na_2O	Not detected
K_2O	00.084
P_2O_5	00.198
Loss on ignition	10.22