Construction and Building Materials 162 (2018) 857–870

Contents lists available at ScienceDirect

Construction and Building Materials

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

Behavior of hybrid-synthetic fiber reinforced cellular lightweight concrete under uniaxial tension – Experimental and analytical studies

Mohammad Abdur Rasheed, S. Suriya Prakash *

Department of Civil Engineering, Indian Institute of Technology, Hyderabad, India

HIGHLIGHTS

- Behavior of hybrid fiber reinforced CLC under uniaxial tension is investigated.
- Dog-bone shaped specimens of 150 mm × 100 mm cross section were cast and tested.
- Synthetic fibers improved the post-cracking behavior of CLC under tension.
- Hybrid fibers showed better performance compared to only macro-structural fibers.
- Variable engagement model is proposed to model the tension behavior.

ARTICLE INFO

Article history:
Received 26 June 2017
Received in revised form 4 December 2017
Accepted 10 December 2017

Keywords:
Cellular lightweight concrete
Digital Image Correlation
Hybrid-synthetic fibers
Low strength building material
Stress-strain curve
Tension

ABSTRACT

This paper investigates the effect of hybrid-synthetic fiber reinforcement on uniaxial tension behavior of low strength cellular lightweight concrete (CLC). Low strength CLC material is increasingly used for structural and non-structural masonry applications. These masonry units of low compressive strength typically offer little resistance to tensile stresses under lateral loading resulting in the collapse of CLC walls. A unique experimental setup was developed to test CLC under uni-axial tension. Dog-bone CLC specimens of length 600 mm and 150 mm × 100 mm cross section (test region) were cast with different synthetic fiber dosages and tested under uni-axial tension. Digital Image Correlation (DIC) technique was used to understand the crack-bridging mechanisms of the fibers. Experimental surface strains and crack openings were inferred using DIC technique. Presence of fibers prevented the premature fracture and led to improved post-cracking stiffness and ductility. Restricted crack localization and improved ductility were also observed due to addition of fiber reinforcement. Analytical models were used to predict the behavior of fiber reinforced cellular lightweight concrete (FRCLC) in tension based on the matrix and fiber parameters. The predictions had a good correlation with the experimental results.

1. Introduction

Cellular lightweight concrete (CLC) is a low density and low strength material used as partition walls, thermal insulation material on roofing systems, soil stabilization, and as infill in concrete and steel frames [1,2]. Its good functional performance such as low density, better acoustic insulation, termite proof and good thermal insulation [3–5] makes it a viable alternative against conventional clay brick masonry. Detailed literature review on the properties and applications of foamed concrete has been studied by researchers in the past [3,6]. Density of typical CLC brick unit is about one-third of the clay brick unit's density. One of the significant advantages of using CLC is reduction in dead weight leading to reduction in the reinforcement required for reinforced concrete frame elements. The large size of CLC blocks ensures faster construction of walls with lesser mortar joints. Large volumes of fly ash used in manufacturing of CLC makes it a sustainable and eco-friendly building material [7]. However, the brittle nature of CLC materials raises concern when it is subjected to flexure, tensile or shear loading.

Addition of fiber reinforcement CLC and in normal concrete has shown to enhance its performance in flexure [8,9]. Peak strength improvement, enhanced ductility and increased toughness index were observed in fiber reinforced CLC when subjected to compression and flexure [8]. Hybrid-synthetic fiber reinforcement, composed of micro and macro fibers, enhances the performance of CLC at both micro and localized cracking stages [8]. Attempts have been made in the past for using fiber reinforced foam concrete for

* Corresponding author.
E-mail addresses: ce13m15p100001@iith.ac.in (M.A. Rasheed), suriyap@iith.ac.in (S.S. Prakash).

https://doi.org/10.1016/j.conbuildmat.2017.12.095
0950-0618/

Nomenclature

NOTATIONS

V_f	Volume Fraction of fibers $= \frac{volume_{fibers}}{volume_{matrix} + volume_{fibers}}$
σ	stress in the specimen
ε	strain applied
$f_{t,FRCLC}$	tension stress in fiber reinforced cellular lightweight concrete
f_{ct}	tension stress due to matrix softening
f_{st}	tension stress due to frictional bond between fiber and matrix
f'_t	tensile strength of control specimen
c	attenuation factor in matrix softening
w_{cr}	crack width
β_f	frictional bond factor
s_f	slip at maximum bond strength
p	porosity factor
α_f	fiber orientation factor
$R.I$	Reinforcing Index
$R.I_{eff}$	Effective Reinforcing Index
l_f	length of fiber
d_f	diameter of fiber
$\tau_{f,max}$	maximum bond strength

structural applications [10]. The growing use of low strength CLC as the masonry elements in the reinforced concrete (RC) framed structures as well as load bearing masonry structures necessitates the knowledge of CLC behavior in tension as well as in compression. CLC material behavior under tension needs to be clearly understood for modelling the behavior of CLC masonry elements under the action of different loading conditions. Stress-strain behavior of CLC material under tension loading is essential for accurate prediction of CLC masonry behavior using any finite element package. This study is a part of project which seeks to understand the mechanical behavior of fiber reinforced CLC (FRCLC). Behavior of FRCLC in compression and flexure has been studied and reported in a companion paper by authors [8]. Composite action of FRCLC along with cement mortar as the layer between successive block has been established through testing masonry prisms. The present study focuses on tension behavior of FRCLC.

In general, performing a tension test on low strength materials like CLC is difficult since it requires sophisticated equipment and instrumentation. Tension properties can be characterized by testing different type of specimens. Notched beams and notched prisms tend to depict the tensile behavior in a localized region, whereas uniaxial tension behavior can be better assessed by testing of dog-bone shaped specimens. A test setup has been developed to investigate the uniaxial tensile behavior. Tension tests were performed on dog-bone shaped CLC specimens with and without hybrid-synthetic fibers. Considerable length of the dog-bone specimen has uniform cross-section for ensuring a realistic material behavior. In order to complement the regular stress-strain curve in tension, a non-contact full field displacement measurement technique is employed.

A renewed interest in the area of non-contact full field measurement techniques to find displacement and strain has been observed in the recent years [11]. In this area of strain measurement, non-interferometric technique is particularly popular due to its low susceptibility towards environmental disturbance. Non-interferometric techniques can further be divided into (i) speckle photography (ii) image correlation and (iii) geometric moiré and grid method. Speckle photography requires rough surface to be illuminated by a coherent light source whereas grid method requires analysis of deformation evolution process of equi-spaced and parallel lines. Digital Image Correlation (DIC) is a modern optical measurement system that allows for virtually continuous measurements of the displacement field of the entire surfaces of tested elements. Based on the displacement field, the strain field is calculated and other interesting information for structural concrete can be inferred, such as crack kinematics and crack branching [12]. The post processing of the images allows tailoring the DIC analysis depending on the known Behavior of the tested element. Because of these advantages, the use of DIC for structural experiments is continuously growing and complementing and becoming a substitute for the standard instrumentation.

2. Research significance

Development of tensile stresses indicates the initiation of damage in any material. Quasi-brittle materials such as CLC, when subjected to compression can fail in the orthogonal direction to loading due to the development of tensile stresses from Poisson's effect [13]. Therefore, establishing the behavior of CLC under tension is of utmost importance before expanding its application. Split tensile testing of cylinders has been used to assess the tensile behavior in the past. However, this method does not give the residual strength after cracking of matrix. Direct tensile behavior of low strength material such as CLC has not been investigated in the past. The reason partly lies in the sophistication involved in developing the test setup. Conventional clamping of the specimen using hydraulic clamps results in local crushing of the low strength CLC material. On the other hand, application of epoxy results in interface failure between the specimen and platen. This study is in continuation of the series of experiments that seeks to characterize the mechanical properties of FRCLC. The prime objectives of this research can be outlined as follows: (1) Develop a novel experimental setup to test low strength CLC in uniaxial tension, (2) Characterize the tensile properties of low strength CLC material with different fiber dosages, (3) Study the crack opening and reduction in crack width due to different combinations of fiber reinforcement with the help of full-field strain measurements using DIC and (4) Develop an analytical model for predicting the tension behavior of CLC material with varying fiber dosage. DIC is an advanced tool for understanding the fracture process and crack arresting mechanisms of FRC. Although more experiments are required to generalize the results, the results presented here provides insights on the tensile behavior of FRCLC and for further investigations of CLC fracture processes.

3. Materials used and casting of specimens

3.1. CLC mix

Fly ash, cement, foam and water are the basic ingredients of a typical CLC mix [14]. These basic ingredients were added in the proportions as shown in Table 1 for casting CLC dog-bone specimens.