Materials and Design 93 (2016) 247–254

Contents lists available at ScienceDirect

Materials and Design

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

Nonlinear flexural behaviour of flax FRP double tube confined coconut fibre reinforced concrete

Jiaxin Chen *, Nawawi Chouw

Department of Civil and Environment Engineering, the University of Auckland, Auckland, New Zealand

ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form 6 December 2015
Accepted 14 December 2015
Available online 30 December 2015

Keywords:
Flax fibre
Fibre reinforced polymer
Coconut fibre
Fibre reinforced concrete
Double flax fibre reinforced polymer tube confinement

ABSTRACT

The flexural performance of coconut fibre reinforced concrete composites, confined with flax fibre reinforced polymer tubes was investigated. Six 520 mm long cylindrical specimens were tested under four-point bending. Two kinds of specimens were considered. The single tube type consists of coconut fibre reinforced concrete confined by a single, outer, flax fibre reinforced polymer tube, whereas the double tube type involves both the outer polymer tube, and a polymer tube running along the centre line of the concrete cylinder. The ultimate load, flexural deformation, and outer tube strains in the longitudinal and hoop directions were experimentally measured. Additionally, the cracking moments and neutral axis depths of both the double tube and single tube confined specimens, were compared. It was found that the double tube specimens possessed excellent flexural characteristics, particularly in comparison to the single tube specimens.

1. Introduction

In recent years, research and engineering interest has been shifting from synthetic fibre-reinforced polymeric materials to natural fibre-reinforced polymeric materials. Synthetic materials such as aramid, carbon and glass fibre reinforced plastics, have now been tested and developed to the stage where they can now be used with confidence in the aerospace, automotive and construction industries. However, because these materials consist of glass/carbon fibres, they have the drawbacks of being high-cost, non-renewable with a low potential for recycling, and are non-biodegradable. In contrast, natural fibres have excellent potential as construction and building materials, and can be used to promote the development of sustainable construction. Research into the mechanical properties and physical performance of various concrete composite materials has been carried out. These studies include the use of coconut outshell [1,2], flax [3–6], sisal, banana [7,8], sugar cane bagasse, bamboo, and jute fibres [9–13]. The results have been mainly encouraging and it has been shown that natural fibre reinforced polymer has a number of useful attributes, i.e. improved tensile strengths and flexural modulus. In the case of natural fibre reinforced concrete post cracking resistance, energy absorbing capability, and fatigue strengths can be enhanced over that associate with the plain concrete. The natural lignocellulosic fibres allow for a concrete mix that is lightweight, environmentally friendly, and relatively cost effective. This is especially advantageous in many developing countries, where such natural fibres are often available in abundance.

More recently, Yan and Chouw [14,15] proposed coconut fibre reinforced concrete (CFRC) structure confined by a flax fibre reinforced polymer (FFRP) tube. This FFRP–CFRC composite structural member combines the advantages of both FFRP and CFRC composites. Flax fabric is used as the reinforcement of the FFRP tube, and confines the concrete, while coir in the cementitious matrix increases the fracture resistant properties of CFRC. Yan and Chouw's studies revealed a number of features of FFRP–CFRC composites. With regard to flexural behaviour, FFRP tubes have the function of providing tensile and shear strength. The stiffness of the FFRP tube strongly influences the flexural behaviour of FFRP tube confined CFRC [16]. However, their work focused only on the confinement effects of the outer FFRP tube.

In recent decades, some researchers and engineers have realised that dual confined concrete structures have outstanding performance in the bending test. The flexural behaviour of concrete-filled double skin steel tube (CFDST) members have been studied by several researchers, including Tao and Han [17,18], Idriss and Ozbakkaloglu [19], Uenaka and Kitoh [20], Fam et al. [21], Li et al. [22], Zhao and Grzebieta [23]. The inner and outer steel tubes can be circular hollow sections, square hollow sections or rectangular hollow sections. Several possible combinations of CFDST members were tested. All results showed that double skin structures display very good flexural characteristics, especially in regard to their strength and ductility. This is because the compressive concrete is confined by the steel tube, and these tubes are capable of simultaneously enhancing the compressive strength, while also

* Corresponding author at: Department of Civil and Environmental Engineering, the University of Auckland, Auckland Mail Centre, Private Bag 92019, Auckland 1142, New Zealand.

E-mail address: Jche872@aucklanduni.ac.nz (J. Chen).

http://dx.doi.org/10.1016/j.matdes.2015.12.069
0264-1275/

providing ductile behaviour. It is noted that these studies of double sandwich structural composites, focused only on the steel confinement. Today, however, steel is typically expensive, and in modern day construction, an average of 200 kg of steel reinforcement (about 8% of the overall weight) is used for each cubic metre of concrete poured [22]. Furthermore, it is only a question of time before steel will corrode. Therefore, there are obvious advantages in promoting the use of cementitious building materials reinforced with natural fibres. Research in this field has promise of contributing significantly to more sustainable construction [24].

In this work, the influence of an inner FFRP tube on the flexural response of a new double FFRP tube reinforced CFRC (DFFRP–CFRC) long cylindrical composite beam is investigated for the first time. This composite consists of double concentric FFRP tubes of the same length. The double FFRP tubes are infilled by CFRC. No conventional reinforcement was used in any of the beams.

2. Experimental work

2.1. Test specimens and materials

Table 1 gives the test matrix of the specimens. It consists of six long cylindrical specimens with a length of 520 mm and a CFRC core diameter of 100 mm. Three of the specimens are of single FFRP tube confined coconut fibre reinforced concrete (FFRP–CFRC), while the other three are double FFRP tubes confined CFRC (DFFRP–CFRC) composite specimens (see Fig. 3). For both FFRP tube, single confined CFRC and double confined CFRC specimens, the outer tube consisted of four layers of flax fabric. The average thickness of the outer tube is 5.3 mm. The inner tube of DFFRP–CFRC was designed using three layers of flax fabric, and this tube had an average wall thickness of 3.05 mm. The four-point bending test was performed until failure, according to ASTM C78 [25].

The material of the FFRP composites used the commercial bidirectional woven flax fabric (500 g/m^2), which has a plain woven structure with a count of 7.4 threads/cm in both the warp and weft directions [4]. The flax fabric was obtained from Libeco, Belgium. The epoxy used was the SP High Modulus Ampreg 22 resin and slow hardener; the mix ratio is 100:26, respectively. Table 2 lists the mechanical properties of flax fibre and epoxy resin. More details of the physical properties of flax, epoxy and the mechanical properties of FFRP composite are provided by Yan [3].

The FFRP tubes were fabricated using the hand lay-up process. This was carried out at the Centre of Advanced Composites Materials (CACM) at the University of Auckland. For the details of the fabrication process of the FFRP tubes, the reader is referred to a previous study [16]. An additional 20 mm length of buffer was provided to the designed cylinder height, with 10 mm at each end in order to ensure that each FFRP tube was of 200 mm length with two cleanly cut ends. The fabric fibre orientation was at 90° from the axial direction of the aluminium tube.

For CFRC, Portland cement, gravel, natural sand, and clean water were used for each specimen. The mix ratio by weight was 1: 0.58: 3.72: 2.37 for cement: water: gravel: and sand, respectively. This mix design follows the ACI Standard 211 [26], and is expected to achieve a 28-day compressive strength of 25 MPa. The coir (extracted from the outer shell of coconuts) was obtained from Bali, Indonesia. The fibres were loosened and separated from one another, and the coir dust removed. The fibres were then manually straightened, combed, and cut into the required lengths (50 mm). The coconut fibres are then added into the concrete during mixing. The mass of the fibres equates to 1% of the overall mass of the cement. The clustering of coconut fibres during the whole casting process was avoided. The coconut fibres were evenly distributed throughout the mix by introducing them to the mix gradually, and also by occasionally stopping the concrete mixer and manually separating the fibres.

Table 2
Mechanical properties of flax fibre and epoxy [16].

Material	Diameter (mm)	Density (g/cm^3)	Elastic modulus (GPa)	Tensile strength (MPa)
Flax fibre	0.708	1.43	16.4	3.2
Epoxy	N/A	1.09	3.6	4.5

After cutting clean both ends of the FFRP tube, one end of the tube was sealed by silicon on a wooden plate as a means of water-proof treatment. A wooden clamp was developed to ensure that the inner FFRP tube is aligned with the longitudinal centre-line of the specimen (Fig. 1(b)). The concrete was then poured, compacted and cured in a standard curing water tank for 28 days. Prior to the experiments, both end surfaces of all FFRP–CFRC cylinders were prepared with plaster to provide both ends with a smooth and uniform surface.

2.2. Instrumentation and test set-up

For each of the four-point bending tests on the cylindrical specimens, six strain gauges and three LVDTs were used (Figs. 2 and 3). Three strain gauges (i.e. gauges H1, H2 and H3) were mounted at the mid-span of each specimen, and aligned along the hoop direction in order to monitor the lateral strain. Three other strain gauges (i.e. gauges A1, A2 and A3) were placed in the longitudinal direction of the tube in order to measure the axial strains. One LVDT was placed under the lower boundary of the specimen at mid-span, in order to measure the deflection, as shown in Fig. 4. Two LVDTs were installed at the end of the specimen in order to measure the relative displacement between the outer FFRP tube and the adjacent concrete (see Figs. 2 and 3). The four-point bending test was conducted using an Instron testing machine in accordance with ASTM C78 [25].

3. Results and discussion

3.1. Test results

The test results (averaged values obtained from three identical specimens) for two different configurations of cylindrical specimens under flexural loading are listed in Table 3. For both configurations of confined concrete specimens, the ability to carry the lateral loading was confirmed. The peak loads of FFRP–CFRC and DFFRP–CFRC specimens are 68.09 kN and 77.71 kN, respectively.

The CFRC core confined by double FFRP tubes not only increased the load carrying capacity by 14% in comparison with single FFRP tube confinement, but also exhibited remarkable tensile strength, as well as ductility. In comparison with FFRP–CFRC structures, the maximum deflection of DFFRP–CFRC structures was slightly reduced by 0.7 mm

Table 1
Specimen configuration.

Configuration	No. of specimens	No. of fabric layers * L_i and L_o	Thickness (mm) * T_i and T_o	Fibre volume fraction (%) inner and outer tube
FFRP–CFRC	3	–; 4	–; 5.3	–; 54
DFFRP–CFRC	3	3; 4	3.05; 5.3	52.5; 54

* L_i and L_o indicates the number of fabric layers of inner tube and outer tube, respectively;
* T_i and T_o corresponds to the thickness of inner tube and outer tube.