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Mechanical and dynamic properties of coconut fibre reinforced concrete

Majid Ali *, Anthony Liu, Hou Sou, Nawawi Chouw

Department of Civil and Environmental Engineering, The University of Auckland, Private Bag 92019, Auckland 1142, New Zealand

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ABSTRACT

Coconut fibres have the highest toughness amongst natural fibres. They have potential to be used as reinforcement in low-cost concrete structures, especially in tropical earthquake regions. For this purpose, the mechanical and dynamic properties of coconut fibre reinforced concrete (CFRC) members need to be well understood. In this work, in addition to mechanical properties, damping ratio and fundamental frequency of simply supported CFRC beams are determined experimentally. A comparison between the static and dynamic moduli is conducted. The influence of 1%, 2%, 3% and 5% fibre contents by mass of cement and fibre lengths of 2.5, 5 and 7.5 cm is investigated. To evaluate the effect of coconut fibres in improving the properties of concrete, the properties of plain concrete are used as a reference. Damping of CFRC beams increases while their fundamental frequency decreases with structural damage. CFRC with higher fibre content has a higher damping but lower dynamic and static modulus of elasticity. It is found that CFRC with a fibre length of 5 cm and a fibre content of 5% has the best properties.

1. Introduction

Researchers have used plant fibres as an alternative of steel or synthetic fibres in composites such as cement paste, mortar and concrete [1–26]. These natural fibres include coconut, sisal, jute, hibiscus cannabinus, eucalyptus grandis pulp, malva, ramie bast, pineapple leaf, kenaf bast, sansevieria leaf, abaca leaf, vakka, date, bamboo, palm, banana, hemp, flax, cotton and sugarcane fibres. Natural fibres are cheap and locally available in many countries. Their use, as a construction material, for improving the properties of the composites costs a very little when compared to the total cost of the composites. Compared to steel fibres, they are also easy to use or handle because of their flexibility, especially when high percentage of fibres is involved. However, in such a case, a methodology for casting needs to be developed. For expressing the quantities of fibres, volume fraction and fibre content are often used [11–16]. Volume fraction can either be part of total volume of composite or part of volume of any ingredient to be replaced. Fibre content can be part of total weight/mass of composite or any ingredient to be replaced. Researchers often investigated the optimum quantity and length of fibres [11–15] to achieve maximum strength of the composite; any further increase or decrease in volume fraction and/or fibre length may reduce the composite strength.

Coconut fibre is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre are coir, cocos nucifera and arecaceae (Palm), respectively. There are two types of coconut fibres, brown fibre extracted from matured coconuts and white fibres extracted from immature coconuts. Brown fibres are thick, strong and have high abrasion resistance, while white fibres are smoother and finer, but also weaker. Coconut fibres are commercially available in three forms, namely bristle (long fibres), mattress (relatively short) and decorticated (mixed fibres). These different types of fibres have different uses depending upon the requirement. In engineering, brown fibres are mostly used. According to official website of International Year for Natural Fibres 2009 [27], approximately, 500,000 tonnes of coconut fibres are produced annually worldwide, mainly in India and Sri Lanka. Its total value is estimated at $100 million. India and Sri Lanka are also the main exporters, followed by Thailand, Vietnam, the Philippines and Indonesia. Around half of the coconut fibres produced is exported in the form of raw fibre. The general advantages of coconut fibres include moth-proof; resistant to fungi and rot, provide excellent insulation against temperature and sound, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, spring back to shape even after constant use. Coconut fibre is the toughest fibre (21.5 MPa) amongst natural fibres (Munawar et al. [28]). They are also capable of taking strain 4–6 times more than that of other fibres (Munawar et al. [28] and Satyanarayana et al. [29]).

Abiola [30] evaluated the mechanical properties (load-extension and stress–strain curves, Young's modulus, yield stress, stress and strain at break) of inner and outer coconut fibres experimentally, and the results were verified by finite element method using a commercial software ABAQUS. The author found that the inner coconut fibre had a higher mechanical strength as compared to that of outer fibre, but the outer coconut fibre had a higher elongation property which enables it to absorb or withstand higher stretching energy.

* Corresponding author.
E-mail address: mali078@aucklanduni.ac.nz (M. Ali).

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Ramakrishna and Sundararajan [31] investigated the variation in chemical composition and tensile strength of four natural fibres, i.e. coconut, sisal, jute and hibiscus cannabinus fibres, when subjected to alternate wetting and drying and continuous immersion for 60 days in water, saturated lime and sodium hydroxide. Chemical composition of all fibres changed because of immersion in the considered solutions. Continuous immersion was found to be critical due to the loss of their tensile strength. However, coconut fibres were reported best for retaining a good percentage of its original tensile strength in all tested conditions.

2. Previous works on coconut fibre reinforced composites

Slate [11] investigated compressive and flexural strength of coconut fibre reinforced mortar. Two cement-sand ratios by weight, 1:2.75 with water cement ratio of 0.54 and 1:4 with water cement ratio of 0.82 were considered. Fibre content was 0.08%, 0.16% and 0.32% by total weight of cement, sand and water. The mortars for both design mixes without any fibres were also tested as reference. Cylinders of 50 mm diameter and 100 mm height and beams of 50 mm width, 50 mm depth and 200 mm length were tested. The curing was done for 8 days only. It was found that, compared to that of plain mortar of both mix designs, all strengths were increased in the case of fibre reinforced mortar with all considered fibre contents. However, a decrease in strength of mortar with an increase of fibre content was also observed.

Cook et al. [12] reported the use of coconut fibre reinforced cement composites as low cost roofing materials. The parameters studied were fibre lengths (2.5, 3.75 and 6.35 cm), fibre volumes (2.5%, 5%, 7.5%, 10% and 15%) and casting pressure (from 1 to 2 MPa with an increment of 0.33 MPa). They concluded that the optimum composite consisted of fibres with a length of 3.75 cm, a fibre volume fraction of 7.5% and is casted under the pressure of 1.67 MPa. A comparison revealed that this composite was much cheaper than locally available roofing materials.

Aziz et al. [13] cited the work of Das Gupta et al. [14,15] who studied the mechanical properties of cement paste composites for different lengths and volume fractions of coconut fibres. Aziz et al. concluded that the tensile strength and modulus of rupture of cement paste increased when fibres up to 38 mm fibre length and 4% volume fraction were used. A further increase in length or volume fraction could reduce the strength of composite. The tensile strength of cement paste composite was 1.9, 2.5, 2.8, 2.2 and 1.5 MPa when it was reinforced with 38 mm long coconut fibre and the volume fractions of 2%, 3%, 4%, 5% and 6%, respectively. The corresponding modulus of rupture was 3.6, 4.9, 5.45, 5.4 and 4.6 MPa, respectively. 4% volume fraction of coconut fibres gave the highest mechanical properties amongst all tested cases. With 4% volume fraction, they also studied the tensile strength of cement paste reinforced with different lengths of coconut fibres. With the fibre lengths of 25, 38 and 50 mm, the reported tensile strength was 2.3, 2.8 and 2.7 MPa, respectively. The results indicated that coconut fibres with a length of 38 mm and a volume fraction of 4% gave the maximum strength.

Paramasivam et al. [16] conducted a feasibility study of coconut fibre reinforced corrugated slabs of 915 mm $\times$ 460 mm $\times$ 10 mm for low-cost housing. A cement–sand ratio of 1:0.5 and water–cement ratio of 0.35 were used. Test for flexural strength using third point loading was performed. For producing required slabs having a flexural strength of 22 MPa, a fibre length of 2.5 cm, a volume fraction of 3%, and a casting pressure of 0.15 MPa were recommended. The thermal conductivity and absorption coefficient for low frequency sound were comparable with those of asbestos boards.

Agopyan et al. [17] studied coir and sisal fibres as replacement of asbestos in roofing tiles. The dimensions of the tiles were 487 mm $\times$ 263 mm $\times$ 6 mm. Three-point bend test specimen with 2% total fibre volume fraction, support span of 350 mm, deflection rate of 5 mm/min was employed for determination of the maximum load. After the ageing periods of 16 and 60 months, the corresponding maximum load taken by coir tile were 235 and 248 N, respectively while that by sisal tiles were 237 and 159 N, respectively. The major benefit of reinforced tiles was their at least 22% higher energy absorption than that of the unreinforced tiles which could help to avoid fragile rupture of tiles during transportation or installation.

John et al. [18] studied the coir fibre reinforced low alkaline cement mortar taken from the internal and external walls of a 12 year old house. The panel of the house was produced using 1:1.5:0.504 (cement:sand:water, by mass) mortar reinforced with 2% of coconut fibres by volume. Fibres removed from the old samples were reported to be undamaged. No significant difference was found in the lignin content of fibres removed from external and internal walls, confirming the durability of coconut fibres in cement composites.

Luisito et al. [19] of PCA-Zamboanga Research Center in Philippines invented coconut fibre boards (CFB) for applications such as tiles, bricks, plywood and hollow blocks. It is used for internal and exterior walls, partitions and ceiling. CFB consisted of 70% cement and 30% fibre by weight. It has water absorption of 32%, water swelling of 4.2% and bending strength of 0.81 MPa, respectively.

Mohammad [20] tested wall panels made of gypsum and cement as binder and coconut fibre as reinforcement. Bending and compressive strength, moisture content, density and water absorption were investigated. As expected, coconut fibres did not contribute to bending strength of the tested wall panels. Compressive strength increased with the addition of coconut fibres. There was no considerable change of moisture content with coconut fibres. However, moisture content increased with time. Water absorption of panels was not significantly affected with an increase in fibre content.

Ramakrishna and Sundararajan [21] carried out the experiments on impact resistance of slabs using a falling weight of 0.475 kg from a height of 200 mm. The slabs consisted of 1:3 cement–sand mortar with the dimension of 300 mm $\times$ 300 mm $\times$ 20 mm. They were reinforced with coconut, sisal, jute and hibiscus cannabinus fibres having four different fibre contents of 0.5%, 1.0%, 1.5% and 2.5% by weight of cement and three fibre lengths of 20, 30 and 40 mm. A fibre content of 2% and a fibre length of 40 mm of coconut fibres showed the best performance by absorbing 253.5 J impact energy. At ultimate failure all fibres, except coconut fibres, showed fibre fracture while coconut fibre showed fibre pull-out. The ultimate failure was determined based on the number of blows required to open a crack in the specimen sufficiently and for the propagation of the crack through the entire depth of the specimen.

Li et al. [22] studied untreated and alkalized coconut fibres with the lengths of 20 mm and 40 mm as reinforcement in cementitious composites. Mortar was mixed in a laboratory mixer at a constant speed of 30 rpm, with cement: sand: water: super plasticizer ratio of 1:3:0.43:0.01 by weight, and fibres were slowly put into the running mixer. The resulting mortar had a better flexural strength (increased up to 12%), higher energy absorption ability (up to 1680%) and a higher ductility (up to 1740%), and is lighter than the conventional mortar.

Reis [23] performed third-point loading tests to investigate the flexural strength, fracture toughness and fracture energy of epoxy polymer concrete reinforced with coconut, sugarcane bagasse and banana fibres. The investigation revealed that fracture toughness and energy of coconut fibre reinforced polymer concrete were the highest, and an increase of flexural strength up to 25% was observed with coconut fibres.

Asasutjarit et al. [24] determined the physical (density, moisture content, water absorption and thickness swelling), mechanical