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Experimental Study on the Mechanical Properties of Coconut Fibre Reinforced Lightweight Foamed Concrete

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Abstract
With the quest for green construction and affordable housing system for both the rural and urban population in Malaysia, various proposals focussing on cutting down conventional building material costs have been put forward. One of the suggestions in the vanguard has been the sourcing, development and use of alternative, non-conventional local construction materials including the prospect of using some agricultural wastes as construction materials. Foamed concrete is good in compression but weak in tension and tends to be brittle. The weakness in tension can be overcome by the inclusion of fibres. The use of fibres also alters the behaviour of the fibre-matrix composite after it has cracked, thereby improving its toughness. This research describes experimental studies on the use of coconut coir fiber as mechanical properties enhancement of foamed concrete which focuses on 3 parameters which are compressive strength, flexural strength and splitting tensile strength with different percentages of coconut fibre (0%, 0.2% and 0.4%). The addition of coconut fiber significantly improved all the properties investigated. The results of the test showed that the compressive strength, flexural strength and splitting tensile strength of the foamed concrete increase as the fiber volume percentage of the coconut coir fiber increased in the concrete mix.

Keywords: foamed concrete, compressive strength, coconut fiber, flexural strength, splitting tensile strength

Introduction
Foresight groups around the world have acknowledged the future need for construction materials that are light, durable, simple to use, economic and yet more environmentally sustainable. One of the suggestions in the vanguard has been the sourcing, development and use of alternative, non-conventional local construction materials including the prospect of using some agricultural wastes as construction materials [1]. Natural reinforcing materials can be obtained at low cost and low levels of energy using local manpower and technology [2]. Utilization of natural fibers as a form of concrete enhancement is of particular interest to less developed regions where conventional construction materials are not readily available or are too expensive [3].

Foamed concrete is known to be a comparatively brittle material when subjected to normal stresses and impact loads, where its tensile strength is just about one tenth of its compressive strength [4]. As a result for these characteristics, foamed concrete flexural members could not support such loads that usually take place during their service life [5]. In the past, foamed concrete member reinforced with continuous reinforcing bars to withstand tensile stresses and compensate for the lack of ductility and strength [6]. In addition, steel reinforcement is utilized to overcome high potentially tensile stresses and shear stresses at critical location in foamed concrete member [7].

Therefore, fibres are brought in as a solution to develop foamed concrete with enhanced flexural and tensile strength, which is a new form of binder that could combine Portland cement in bonding with cement matrices. Fibres are most generally discontinuous, randomly distributed throughout the cement matrices. The inclusion of fibres in foamed concrete is to delay and control the tensile cracking of composite material. Fibres thus transform inherent unstable tensile crack propagation to a slow controlled crack growth. This crack controlling property of fibre reinforcement delays the initiation of flexural and shears cracking. It imparts extensive post cracking behaviour and extensively enhances the ductility of the

Coconut fibre obtained from coconut husk, belonging to the family of palm fibres, is agricultural waste products obtained in the processing of coconut oil, and is obtainable in large quantities in the tropical regions of the world, most especially in Asia, Africa and southern America [8]. In Malaysia, they are available in large quantities. Coconut fibre is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre is Coir, Cocos nucifera and Arecaceae (Palm), respectively. There are 2 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 [9]. White fibres are smoother and finer, but also weaker. Coconut fibres are commercial 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.

Fig. 1: Raw coconut fibres

Fig. 1 shows raw coconut fibres. There are many general advantages of coconut fibres e.g. they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use, totally static free and easy to clean. Coconut fibre also has been used to enhance concrete and mortar, and has proven to improve the brittleness, ductility and toughness of the concrete and mortar [10].

This study focuses on mechanical properties of lightweight foamed concrete with the addition of coconut fiber of different percentages. Fibers, which are at random dispersed throughout the foamed concrete, could overcome cracks and control shrinkage more efficiently [11]. These materials have exceptional combinations of strength and energy absorption capacity. In general, the fiber reinforcement is not a substitution to conventional steel reinforcement [12]. The fibers and steel reinforcement have their own role in foamed concrete technology. Thus, many applications in which both fibers and continuous reinforcing steel bars can be used together [13]. Nevertheless, fibers are not efficient in withstanding the tensile stresses compared to conventional steel reinforcements [14].

2. Materials, Experimental Setup and Mix Proportion

Portland Cement SEM 1 is used in this study. Uncrushed fine aggregates are used in mortar mixes as a constituent material with a specific gravity of 2.83 and a maximum aggregate size of 5mm with fitness modulus of 3.26. In this study, natural coconut fiber is used. The fibers with length 34mm and different fibers volume fraction ranging which is 0.2% and 0.4% by weight of total mix volume. The water cement ratio is about 0.45 to achieve reasonable workability. The protein foaming agent was used, known as “NORAITE PA-1,” was also manufactured in Malaysia. The foaming agent was diluted in water with a ratio of 1:33 by water volume. No segregation was observed during mixing.

Total specimens for this test are three 100x100x100mm cubes subject to compression loading, three 100x100x500mm prisms subject to flexural loading and three 100x300mm cylinders subject to splitting loading. These entire samples were test at day 7 and 28 curing after one day in the oven. A ratio of 1:1.5:0.45 of cement: sand: water was used in this study to fabricate 1350 kg/m^3 density foamed concrete. The mixture of all materials needs to be blended well, as it will affect the mix. The best mixing time to get a good mix is between 15 to 20 minutes depending on the density of foamed concrete.

3. Results and Discussion

3.1 Compressive Strength

The samples were tested by applying increasing compressive load until failure. Fig. 1 shows the comparison of compressive strength of different percentages of CF at 7 and 28 days. It can be seen from Fig. 1 that the foamed concrete with 0.4% CF has the highest compressive strength (8.63N/mm^2) and the lowest strength is control foamed concrete (6.84N/mm^2) at 28 days. At early age of 7 days, the compressive strength of mixes containing 0.2% and 0.4% CF were 6.22N/mm2 and 6.75N/mm2 respectively as against that of normal mix 5.82N/mm^2. At 28 days, the strength of control 6.84N/mm^2 increase to 7.75N/mm^2 and 8.63N/mm^2 when 0.2% and 0.4% CF is added. The strength gained was up to 12% and 21%. By adding the coir fibre in the mix, the strength boost linearly with increasing fibre contents.

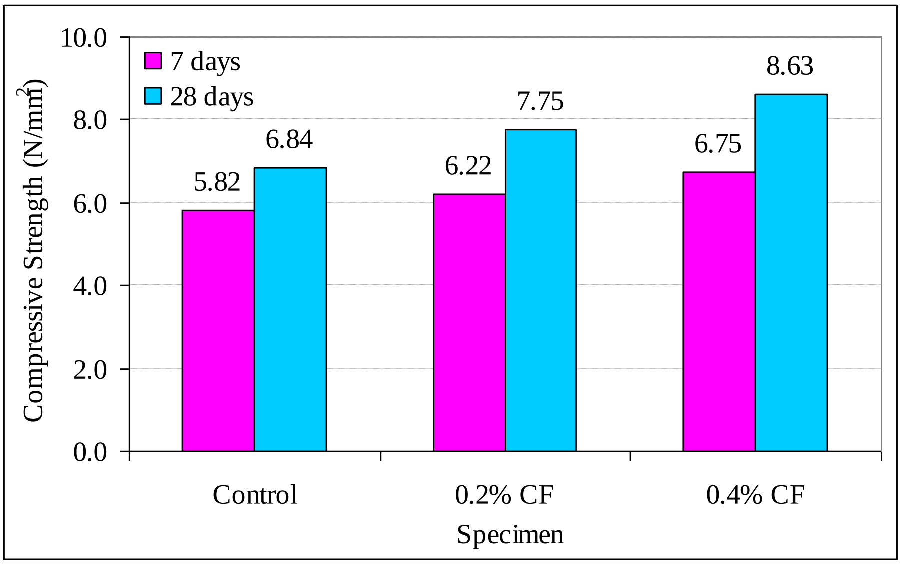


Fig. 1: Compressive strength at 7 and 28 days

3.2 Flexural Strength

Result of the flexural strength test for all the lightweight mixes containing different percentage of CF presented in Fig. 2. It is observed that the flexural strength increased in fiber percentage 0.2% and 0.4% for all the ages. At the age 7 days, flexural strength increase from 0.68N/mm^2 for control to 0.84N/mm^2 for 0.2% CF and representing 1.07N/mm^2 for 0.4%. Also at 28 days, the flexural strength were 0.81N/mm^2 for the control foamed concrete, increased to 1.03N/mm^2 and 1.28N/mm^2 for 0.2% and 0.4% CF

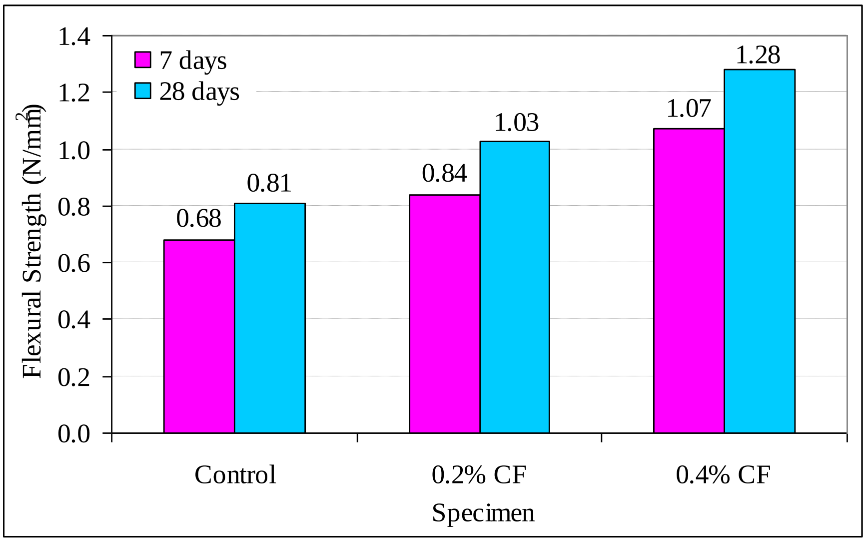


Fig. 2: Flexural strength at 7 and 28 days

3.3 Splitting Tensile Strength

The splitting tensile strength results are shown in Fig. 3. The recorded splitting tensile strength for all mixes with addition of CF shows higher strength compared to the control foamed concrete. On can be observed in compressive strength and flexural strength, it could be said that increase in the percentages of CF, also increase the tensile strength. The increase at age 7 days was found to be up to 9% and 7% from control mix to 0.2% CF and 0.4% CF. It can be easily observed that 0.4% addition of CF had given the highest splitting tensile strength amongst all the samples tested.

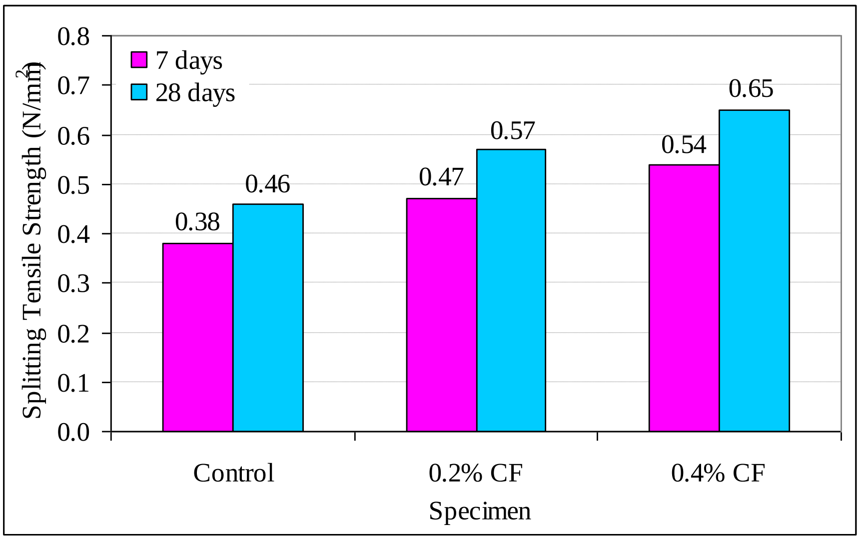
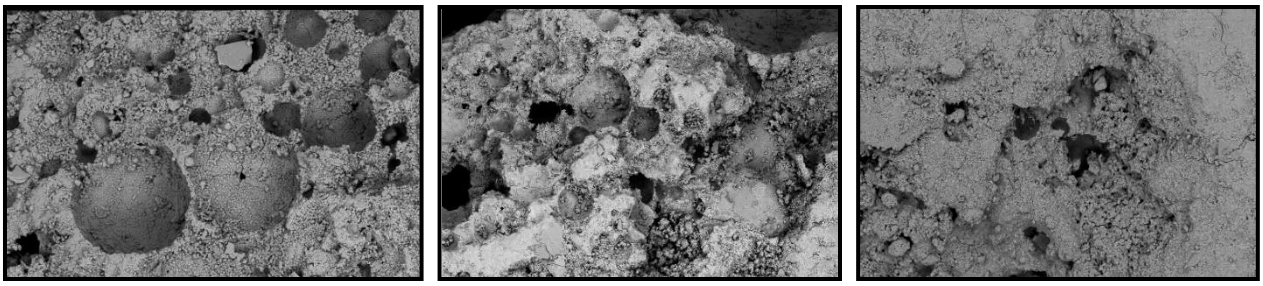


Fig. 3: Splitting tensile strength at 7 and 28 days

3.4 Scanning electron microscope (SEM)

The microstructure of three foamed concrete mixes with different percentages of CF through the SEM observation is shown in Fig. 4. The percentages of CF affect the size of pores produced. For control foamed concrete, formation of pores were bigger compared to foamed concrete with inclusion of CF. Coir fibre as additives reduces the amount and size of pores. On average, the pore size becomes smaller, the increase mass density and compressive strength with comparable percentage. Fly Coir fibre also helps in producing a more uniform distribution of the air voids. Thus, it will prevent bubbles from merging with each other and provide a uniform coating on each of bubbles.



(a) Control Foamed Concrete (b) with 0.2% Coir Fibre (c) with 0.4% Coir Fibre

Fig. 4: Comparison of formation of pores with normal foamed concrete (control) with foamed concrete with different percentages of coir (Magnification level 40x)

Conclusions

The findings of experimental investigations on the potential of coconut coir fiber in lightweight foamed concrete for mechanical properties improvement are reported in this study. The addition of coir fiber significantly improved the strength of the foamed concrete. Different percentages give different mechanical properties of lightweight foam concrete. Lightweight foamed concrete mix added with 0.4% CF shows the highest strength compared to others mixes. SEM analysis for 0.4% CF shows the small size and number of pores that increase the bonding in the cement paste. It is concluded that coconut fibers have the potential to be used in composites for different purposes. Since the use of coconut fibers has given some excellent products, there is still possibility of the invention of new products containing coconut fibers with improved results. There is a need of investigating the behavior of coconut fiber reinforced concrete to be used in main structural components like beams and columns

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