Mechanical properties and flexure behaviour of lightweight foamed concrete incorporating coir fibre

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Abstract. This paper presents an experimental investigation on the mechanical properties and flexural behaviour of lightweight foamed concrete (LFC) with added coir fibre as filler. The compressive strength (\(P_t\)), tensile strength (\(F_t\)), modulus of elasticity (\(E\)), ultimate load and crack pattern of the foamed concrete were determined. The coir fibre was added to the foamed concrete mixture at 0.1%, 0.2% and 0.3% of the total weight of cement. Effects of various percentage of coir fibre used on foam concrete’s mechanical and properties and flexural behaviour were studied and analysed. It was found that the increase percentage of fibre resulted in increase in compressive strength, tensile strength and modulus of elasticity of LFC mixture. LFC with added coir of 0.3% experienced the smallest crack propagation.

1. Introduction

Agriculture is the main source of economy for Malaysia especially in term of development. In human life, agricultural materials played an important role especially as food resources. However, waste product from agriculture industries have not been managed properly. In the past years, Malaysia had recorded 998 billion tons of agricultural waste. These waste were often thrown at landfills and only small amount of them were recycled. This has contributed to the environmental pollution that keeps occurring in Malaysia.

In Malaysia, currently two methods are practiced in managing the waste from coconut plant; either disposed to landfills or combustion process of the coconut fibre. These practices produce more disadvantages rather than advantages. The least desirable method for disposing of waste although sometimes it is necessary. However, when decreasing amount of coconut fibre in the landfills will causes problem for disposed space. Meanwhile, poor operated landfill cause many problems and uncontrolled dumping area. Generally, farmer make an easy decision with burning the coconut fibre. This activity resulted with the release of gas emission to the atmosphere, thus contribute to pollution.

Solid wastes from construction site and plantation produces a huge amount of waste material. In Malaysia, this problem is a huge issue which will cause the environmental problem if it is not managed properly [1]. An investigation had to be done to solve this problem by using it in construction material by undergoing some process. In the past, researcher have used plant fibre as an alternative source of
steel and artificial fibres to be used in composites such as cement paste, mortar and foamed concrete to increase its strength properties [2]. Some of the plant fibre are coir, pineapple leaf, bamboo, palm, banana, cotton and sugarcane which have found that the use of these plant, as additive in foamed concrete mixture, plus it is economical for increasing the tensile strength, shear strength, flexure strength and lightweight from the current concrete mixture.

One of the key in green manufacturing is the effective utilization of resources [3]. Previous researchers have used plant fibres as an alternative source of steel and artificial fibres to be used in composites such as cement paste, mortar and concrete to increase its strength properties. These plant fibres include coir, sisal, jute, ramie bast, pineapple leaf, kenaf bast, sansevieria leaf, abaca leaf, date, bamboo, palm, banana, hemp, flax, cotton and sugarcane [4, 5, 6, 7, 8, 9 and 10]. Majid [2] found that the use of these plant or natural fibres, as reinforcement of composites (such as cement paste, mortar and/or concrete), are economical for increasing their tensile strength, shear strength, toughness and/or combinations of these [2]. Coir fibre can be utilized as materials in concrete due to its advantages such as resistance to the fungi and rot, insulation against temperature and sound, tough and durable, not combustible and resilient. Moreover, coconut fibre is also one of the substance that can be commercialized and recycled, and can be used in fired clay brick and in the concrete mixture. Therefore, this study is conducted to investigate the mechanical properties and flexure behaviour of LFC incorporating coir fibre.

2. Coir Fibre

Coir is a natural fibre extracted from the outer shell of coconut fruit. The size and shape of the coconut makes it possible to float on water and that is why coconut tree are commonly seen near a beach due to this factor. Usually, the length of the fibre varies from 0.3 to 250 mm but for the average length range from 100 to 200 mm [11]. Coconut tree, coconut and fibre were shown below in Figure 1.

Coir fibre is very tough and stiff due to volume of lignin when compare with other natural fibre. The bulk of the ground tissue of the husk, on the other hand is made up of pectin and hemicelluloses [12]. There are many other advantages of coconut fibre such resistant to fungi and rot, provide good insulation against temperature and sound, tough and durable, not easily combustible and easy to clean. This characteristic were benefic ial in order to be use in the foamed concrete later.

The highest agricultural waste which represent a large quantity in the tropical contribute by coconut fibre. Sri Lanka and India are considered to be the major attribution in producing coir fibre to the world [13]. As the population increase, the coconut fibre waste also increase. The current waste disposal practice of incineration within the industry is normally done in an uncontrolled manner and contributes significantly to atmosphere pollution. Meanwhile, improper act taken by farmers in open burning to distinguish coconut fibre has polluted the environment. Thus, previous researchers have found new technology to recycle the coconut fibre by producing various product based on current demand such as rope, mat and tools for rowing.

![Figure 1. (a) Coconut tree and (b) Coconut fibre](image-url)
Brown coconut fibre extracted from seasoned coconut which lose their green colour after undergoing process (<12 month) [12]. Its characteristics are thick, strong and high abrasion resistance. The mature brown coir fibre contain more lignin and less cellulose than fibres such as flax and cotton; therefore, they are stronger but less flexible. Coir bristle can also be bleached and dyed to obtain hanks of different colour [12]. It will be too coarse before being washed and dried. Brown fibre widely used for brushed, coir mattress, doormats and other household products. Table 1 and Table 2 show the chemical composition of coir from previous research and properties of several natural fibres, respectively.

Table 1: Chemical composition of coir.

| Fibre | Hemi-cellulose (%) | Cellulose (%) | Lignin (%) | References |
|-------|--------------------|---------------|------------|------------|
| Coir  | 31.1^a             | 33.2^b        | 20.5^b     | Ramakrishna, et al. (2005a) [5] |
|       | 15 – 28^b          | 35 – 60^b     | 25 – 48^b  | Agopyan, et al. (2005) [6] |
|       | 16.8               | 68.9          | 32.1       | Asasutjarit, et al. (2007) [14] |

Table 2: Properties of natural fibres [12]

| Fibres  | Specific Gravity | Tensile strength (MPa) |
|---------|------------------|------------------------|
| Sisal   | 1.370            | 347 - 378              |
| Coconut | 1.177            | 95 - 118               |
| Bamboo  | 1.158            | 73 - 505               |
| Jute    | 1.020 – 1.040    | 250 - 350              |
| Rice straw | 1.020 – 1.040 | 48                     |

3. Material and methods
The LFC mixture’s proportion of cement, sand and water is 1:2:0.55. The target density is 1400 kg/m³. Thus, water-cement ratio were set up at 0.55. Brown coconut fibre or coir was used as filler in foamed concrete with 0.1%, 0.2% and 0.3% by total weight of mixture. The coir cut into 2mm to smoothen the process of mixing foamed concrete. Figure 2 shows the preparation of cubes and cylindrical specimens for the experiment.

A series of compressive test on cube and cylinder specimens, split tensile test on cylinder specimens and four point bending load test on prism specimens containing coconut fibre were conducted.

4. Result and analysis
Compressive strength for control specimens at 7 days were recorded at 4.4 MPa and increased to 6.5 MPa at 28 days of curing age as shown in Figure 3. This represents an increment of strength around 50%. Aldridge, (2005) state that the compressive strength of foamed concrete with density 1400 kg/m³ is in the range between 7.5 MPa to 10.0 MPa [15]. Therefore, the obtained compressive strength of the control specimen of foamed concrete is in good agreement with the work conducted by Aldridge [15].
Meanwhile, for foamed concrete containing 0.1% coconut fibre, the compressive strength is 5.5 MPa at 7 days to 7.0 MPa at 28 days. The increment is around 31%. Foamed concrete contain 0.2% of coconut fibre shows 35% increment, which is 6.0 MPa at 7 days to 8.1 MPa at 28 days. Compressive strength of foamed concrete containing 0.3% of coconut fibre at 7 days is 6.6 MPa and increased to 8.1 MPa at 28 days. This represents an increment of 24%.

Based on study conducted by Ibrahim et al. (2016), compressive strength of foamed concrete with added fibrous material achieved strength of 7.42 MPa at 28 days [16]. It is proven similar for foamed concrete incorporating coir which achieved higher strength compared to plain LFC at 28 days.

![Figure 3. Graph of cube compressive strength versus days.](image)

Figure 3 shows the trend of development of the tensile strength of the foamed concrete. Based on the graph, it is noticed that the foam concrete’s strength increased with the increase of coconut fibre added. The figure shows that control specimen recorded the lowest tensile strength of 0.93 MPa. The highest tensile strength was 1.53 MPa obtained in foamed concrete with added 0.3% coconut fibre. Generally, the tensile strength increased uniformly from 0.93 MPa, 0.96 MPa, 1.01 MPa and 1.53 MPa for control specimen, 0.1% specimen, 0.2% specimen, and 0.3% specimen respectively. From the results, it can be predicted that the increase of percentage of coconut fibre added in the foamed concrete resulted in greater adhesion in foam concrete.

![Figure 4. Graph of splitting tensile strength versus days.](image)

From Table 3, it is found that the modulus of elasticity for control sample is 8.667 N/mm², which was the least value among the specimen tested. The modulus of elasticity, MOE of foamed concrete specimen with 0.1% coir was increased to 11.050 N/mm² from the control specimen. The specimen with added 0.2% coir achieved MOE value of 11.064 N/mm². The highest value of MOE was obtained in
foamed concrete specimen with added 0.3%, which is 17.143 N/mm². From these results, it can be concluded that higher percentage of coir fibre added in the foam concrete, the higher its MOE would become.

| Foamed concrete with added Coir | 0%     | 0.1%   | 0.2%   | 0.3%   |
|--------------------------------|--------|--------|--------|--------|
| Modulus of Elasticity, E (kN/mm²) | 8.667  | 11.050 | 11.064 | 17.143 |

Figure 5 showed that higher percentage of coir fibre added in the LFC mixture resulted with higher ultimate flexure load. This is due to higher tensile strength and modulus of elasticity obtained by the LFC incorporating coir fibre. It shows that this LFC obtain ductility property when it is added with coir fibre.

The control prism experienced the extreme crack propagation where it finally broke into two at its ultimate load. Figure 6 shows that the foamed concrete with added 0.1% coir shows a vertical early crack. The similar trend was observed in the foamed concrete specimen with added coir of 0.2%. Foamed concrete with added coir of 0.3% experienced the smallest crack propagation. Based on the observation, it can be concluded that the addition of coir in foamed concrete has a significant effect on both the flexural strength and crack pattern of foamed concrete. The high percentages of coir added have proven that it is able to control the crack propagation.
5. Conclusion
The experimental study provide positive and favorable results. The high compressive of were achieved by foamed concrete containing 0.3% coconut fiber. Meanwhile, compressive strength of controlled foamed concrete only at 28 days curing ages. Tensile strength shows that achieved good tensile strength around of controlled ages and increase as the total volume of coconut fiber increase.

Modulus of elasticity indicate that the increment of total fraction increase the strength and the 0.3% of coconut fiber mixture were highest of the specimen. The ultimate crack pattern was decrease as the total volume fraction increase and shows the strength were highest at 0.3% of coconut fiber by obtained.

Based on the experimental study, the compressive strength of foamed concrete containing coconut fiber increase with the increment of volume fraction of coconut fiber. The addition of coconut fiber significantly improves toughness, compressive strength of foamed concrete, tensile strength, modulus of elasticity and minimum the crack pattern of foamed concrete containing coconut fiber. Moreover, the present of coconut fiber decrease the dry density of foamed concrete lower than 1600 kg/m³. Despite its excellent, the use of coconut fiber as additive material in foamed concrete can be applied in construction. Experimental study shows that natural fiber as additive or reinforcement in concrete is viable and cost effective alternative to conventional building material.

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