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Effect of Ramie Fibre on Mechanical Properties of Lightweight Foamed Concrete

Md Azree Othuman Mydin[1*]

[1]*School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia*

**Corresponding author's E-mail: azree@usm.my*

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ABSTRACT

Lightweight foamed concrete (LFC) is good in compression but poor in tension, as it produces multiple microcracks. LFC cannot withstand the tensile stress induced by applied forces without additional reinforcing elements. This study was conducted to assess the potential utilisation of ramie fibre reinforced LFC in terms of its mechanical properties. Density of 600 kg/m^3 was cast and tested with 4 different weight fractions of ramie fibre, which were 0.2, 0.4, 0.6 and 0.8 %. The mechanical properties examined were compressive strength, flexural strength and tensile strength. The results revealed that the addition of 0.6 % of ramie fibre into LFC aids to give the best results for the compressive strength, flexural strength and splitting tensile strength. The existence of ramie fibre in LFC facilitated in evading the promulgation of cracks in the plastic state in the cementitious matrix when the load was applied.

Keywords: Foamed concrete; compressive strength; flexural; splitting tensile.

INTRODUCTION

Lightweight foamed concrete (LFC) was first patented in the year 1923 and a limited scale of the invention was initiated in 1923 [1]. The utilization of LFC was very restricted until the late 1970s when it was started to be expanded in the Netherlands for void filling works. In 1987 a full-scale assessment on the application of LFC as a trench reinstatement was carried out in the United Kingdom and the achievement of this trial led to the extensive application of FC for trench reinstatement and other applications followed [2]. Since then, FC as a building material has become more widespread with expanding production and range of applications [3]. Over the past 20 years, FC has primarily been used around the world for bulk filling, trench reinstatements, backfill to retaining walls and bridge abutments, insulation to foundations and roof tiles, sound insulation, FC soils (especially in the construction of embankment slopes), grouting for tunnel works, sandwich filling for precast units and pipeline infill. Though, in the last few years, there is developing interest in using FC as a lightweight non-structural and semi-structural material in buildings to take benefit from its lightweight and good insulation properties [4].

LFC is established to be a relatively brittle material when subjected to normal stresses and impact loads, where its tensile strength is just about one-tenth of its compressive strength. Therefore, LFC members reinforced with continuous reinforcing bars to withstand tensile stresses and compensate for the lack of ductility and strength [5]. In addition, steel reinforcement is used to overcome high potentially tensile stresses and shear stresses at a critical location in FC members. Even though the addition of steel reinforcement considerably increases the strength of FC, the development of micro-cracks must be controlled to fabricate concrete with homogenous tensile properties. The utilization of lightweight foamed concrete (LFC) has obtained a great interest in the construction industry [6]. It is because the use of LFC will permit high flowability, low density, lightweight and exceptional thermal properties. However, LFC has restricted applications due to its brittleness, especially in the fields that demand high impact, vibration, and fracture strength [7]. Thus, considerations have been given to enhance the usefulness of LFC and one of the ways is by adding fibres.

One of the recommendations at the forefront 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 [8]. Natural reinforcing materials can be obtained at very low cost and low levels of energy using local manpower and technology. The utilization of natural fibres 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 [9].

Synthetic (carbon, polypropylene, polyester, and nylon), steel, natural (such as wood-based) and glass are the four main types of fibre materials that are frequently used [10]. The use of different types of fibre materials has been shown to have various benefits [11,12]. For example, synthetic fibres have high strength, high modulus, lightweight and are easy to install. Then, steel fibres are usually employed fibres for structural applications. Meanwhile, natural fibres are eco-friendly, low energy consumption during processing, has renewable and biodegradable nature and are cheaper than synthetic fibres. Additionally, the current concern for ecology has sparked a propensity toward the use of environmentally friendly materials all over the world [13,14]. Hence, ramie fibre can be used to improve the properties of concrete as it is a 100 % natural, non-hazardous, and biodegradable material.

Integration of plant fibres into LFC improves its mechanical and durability performance. It has been shown that a low volumetric of the short plant fibres decreases the effect of early age on the mechanical properties of concrete. It is crucial to discern the number of fibres, cement, sand, water, and foaming agent in the mixture. There were some efforts by various researchers to ascertain the durability and engineering properties of LFC reinforced by plant and synthetic fibres. Nensok Hassan *et al.* [15] embarked on research efforts using banana fibre in lightweight foamed concrete. They found that banana fibre acted well in the cementitious composite to enhance the attachment between the cement matrix of LFC and the fibre improved the durability and engineering properties of the composite. Comparable research attempts were accomplished with the inclusion of steel fibre. The research discovered that the lightweight foamed concrete composites' durability properties reduced with a rise in the steel weight fraction compared to the control specimen. These results revealed that while banana plant fibre improves lightweight foamed concrete mechanical and durability properties, steel fibre reduces the durability performance. Raj et al.

[16] appraised the engineering performance of foamed concrete reinforced with polyvinyl alcohol fibre and coconut fibre. They found that lightweight foamed concrete strengthened with coconut fibre behaves better than that intensified with polyvinyl alcohol fibre.

From the above review, the influence of ramie fibre addition in LFC for mechanical properties improvement is not well discovered and established. Therefore, this research focuses on establishing the LFC mechanical properties strengthened with ramie fibre. Low-density LFC of 600 was made with different weight fractions of ramie fibre and the composites' mechanical properties were examined.

METHODOLOGY

Materials

LFC consists of a key and additional component such as ordinary Portland cement, fine sand, water, stable foam, and ramie fibre. A constant water-cement ratio of 0.45 was used for all batches of LFC specimens made for this study as it had achieved reasonable workability of foamed mortar. All mentioned materials will be described in detail in the sub-sections below.

Ordinary Portland cement

Cement is the most dominant binder in foamed concrete. The type of cement used was ordinary Portland cement (OPC). Table 1 shows the chemical composition of cement used in this study.

Fine sand

The fine aggregate used was natural fine sand obtained from a local distributor. The fine sand was with a maximum width of 2 mm and a 600-micron sieve, and a passage of 60 to 90 %. The fine sand used was local natural sand. Figure 1 demonstrates the sieve analysis result of the fine sand.

Table 1: Chemical composition of cement

S/No.	Oxides	Composition (%)
1	Silicon dioxide (SiO_2)	16.84
2	Ferric Oxide (Fe_2O_3)	2.64
3	Calcium Oxide	65.95
4	Aluminium Oxide	5.82
5	Magnesium Oxide	1.49
6	Potassium Oxide	0.87
7	Phosphorus Oxide	0.08
8	Sulphur Oxide	2.76
9	Loss of Ignition	-

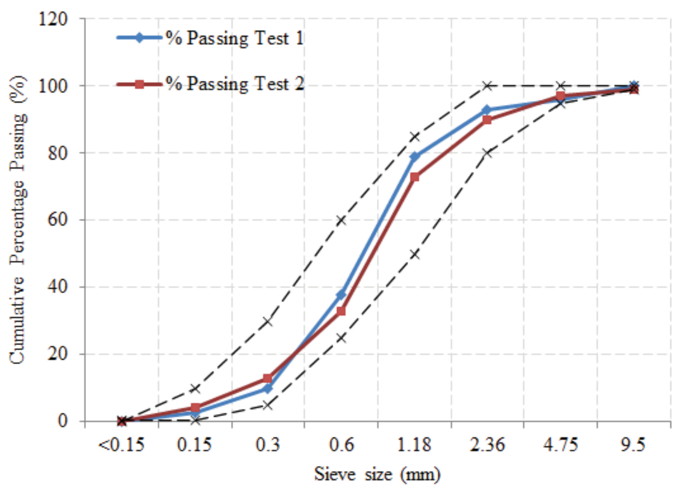

Figure 1: Sieve analysis result of fine sand

Water

The quality of water used counts in the production of foamed concrete. The water used was clean and normal tap water. The water-cement ratio used for this research was 0.45 because this ratio can achieve reasonable workability, based on previous research.

Surfactant

The protein-based foaming agent specifically, Noraite PA-1 was selected to be utilized in this study due to its stable and smaller bubbles and its stronger bonding structure of the bubbles in comparison to the synthetic-based surfactant. The ratio between surfactant and water used was 1:30. In turn, to create a stable foam, 1 litre of protein surfactant was diluted into 32 litres of water. Portafoam TM-2 foam generator was used to produce stable foam which has a volume weight of approximately 2 gram/litre.

Fibre

Ramie fibre was used in this exploration. The ramie fibre was supplied by DRN Technologies Sdn Bhd. Ramie fibre was cleaned until it was free from grease and placed under the sun to dry. Table 2, Table 3 and Table 4 show the chemical composition, physical properties and mechanical properties of ramie fibre utilized in this study, respectively. Electron microscopy was accomplished using the secondary electron mode to characterize the natural lignocellulosic fibres' surface structure. The ramie fibre samples were dried under vacuum and coated with a thin layer of the gold layer before observation to get rid of the effects of charging during image collection. Figure 2 shows the SEM micrograph of ramie fibre used in this study. The weight fraction of the ramie fibre used was 0.2, 0.4, 0.6 and 0.8 % of the total weight mix volume.

Table 2: Chemical composition of ramie fibre

Composition	*Percentage*
Cellulose (%)	*70.1*
Hemicellulose (%)	*10.2*
Lignin (%)	*9.3*
Ash (%)	*2.1*
Pectin (%)	*1.1*
Wax (%)	*0.3*
Moisture (%)	*6.9*

Table 3: Chemical composition of ramie fibre

Element	*Properties*
Diameter (μm)	*155*
Fibre length (mm)	*25*
Density (kg/m^3)	*1470*
Micro-fibrillar angle (°)	*7.5*

Table 4: Mechanical properties of ramie fibre

Element	*Properties*
Tensile strength (MPa)	*321.5*
Young's modulus (GPa)	*16.7*
Torsional Rigidity (10^{-9}N/m^2)	*1.35*
Elongation at break (%)	*8.95*
Poisson's ratio (v)	*0.45*

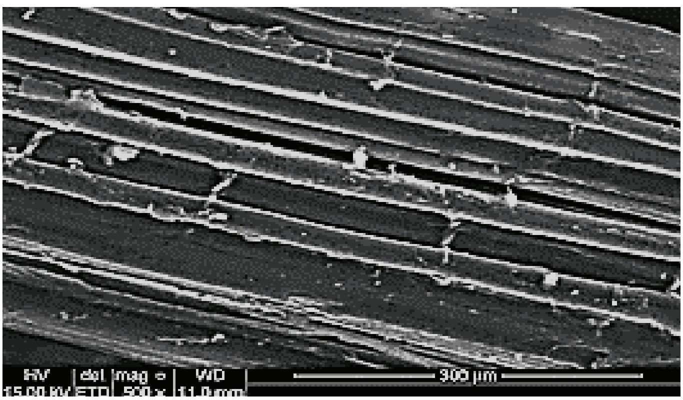

Figure 2: SEM micrograph of ramie fibre

Mix Design

For this research, five mixes were prepared. The density chosen was 600 kg/m^3. The volume fractions of ramie fibre (RF) were 0.2, 0.4, 0.6 and 0.8 %. For entire LFC mixes, the sand-cement ratio was fixed at 1:1.5, and the water-cement ratio was 0.45. Table 5 shows the mix proportion considered in this study.

Table 5: Mix proportions

Specimen	*Mix Density (kg/m³)*	*Mix Ratio (s:c:w)*	Cement (kg)	Fine sand (kg)	Water (kg)	Ramie Fibre (kg)
0.00 % RF	*600*	*1.5:1:0.45*	*46.05*	*69.07*	20.72	0.000
0.20 % RF	600	1.5:1:0.45	46.05	69.07	20.72	0.272
0.40 % RF	600	1.5:1:0.45	46.05	69.07	20.72	0.004
0.60 % RF	600	1.5:1:0.45	46.05	69.07	20.72	0.018
0.80 % RF	600	1.5:1:0.45	46.05	69.07	20.72	0.368

Curing Method

After 24 h, all specimens were demoulded and wrapped with a plastic sheet before testing for 7, 28, and 56 days. The curing purpose is to maintain the proper moisture and temperature of the concrete to ensure continuous hydration. Curing was also undertaken to improve the strength of the concrete along with the age of the concrete to achieve the design strength of the FC.

EXPERIMENTAL SETUP

The compression test was conducted according to the BS12390-3 standard [17] via GoTech GT-7001-BS300 Universal Testing Machine as per shown in Figure 3. The sample size was 100 mm x 100 mm x 100 mm cube. The maximum load and compressive strength were recorded.

Three-point bending test opted in accordance with ASTM International C293 standard [18] as been demonstrated in Figure 4. The sample size was 100 mm x 100 mm x 500 mm prism using GoTech GT-7001-C10 Universal Testing Machine to determine the bending stress.

A splitting tensile strength test of LFC was performed using GoTech GT-7001-BS300 Universal Testing Machine. The maximum load and splitting tensile strength were recorded by ASTM International C496 standard [19]. The specimen size was 100 mm in diameter x 200 mm in height cylinder. Figure 5 visualizes the setup for the splitting tensile test.

Figure 3: Compression test

Figure 4: Bending test

Figure 5: Splitting tensile

RESULTS AND DISCUSSION

Splitting tensile strength

Figure 6 demonstrates the trend concerning the development of the splitting tensile strength of LFC. The splitting tensile strength increased noticeably from the control (0.0 %) up to the inclusion of a 0.6 % weight fraction of ramie fibre. The trend of the growth in the splitting tensile strength of LFC with the addition of ramie fibre was ascribed to the elasticity of the ramie fibre, which can stretch and bond effectively with the cement matrix to avoid cracking. Subsequently, the splitting tensile strength dropped when 0.8 % of ramie fibre was added. The highest splitting tensile strength was 0.37 N/mm^2, which was at day-56 with the inclusion of 0.6 % ramie fibre. The lowest splitting tensile strength was 0.13 N/mm^2, which was the control LFC (0.0 % ramie fibre) on day-7. The splitting tensile strength of LFC accomplished in this investigation is about 60 % of its flexural strength. As shown in Table 4, the elongation at break for ramie fibre is considered excellent (8.95 %), resulting in high tensile strength. Elongation at break expresses the ability of fibre to withstand alterations of shape without crack formation. Natural fibre such as ramie fibre is stiff, thus promoting improving the splitting tensile strength. LFC is understood to have low tensile strength and brittle nature [20]. However, based on the experimental results obtained in this study, the tensile strength was indicated to grow due to the existence of ramie fibre in the cementitious matrix of LFC. The increase of tensile strength is due to the increase in toughness of LFC due to the presence of ramie fibre where 0.6 % weight fraction of fibre addition augments the raise of tensile strength in LFC by encouraging ideal pozzolanic response with ordinary Portland cement, therefore creating stronger LFC [21].

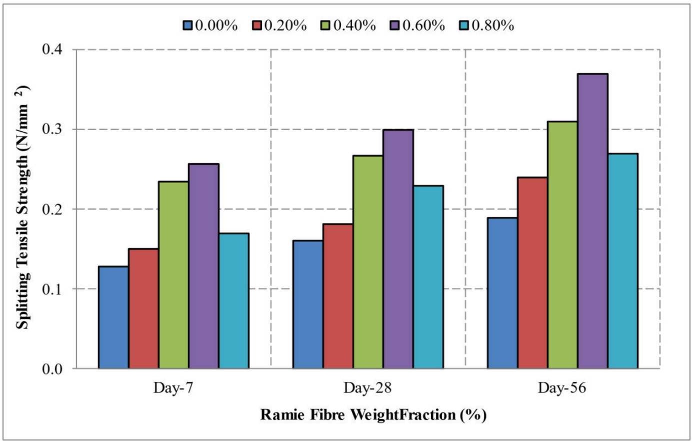

Figure 6: Splitting tensile strength of LFC with different volume fractions of ramie fibre

Bending strength

Figure 7 reveals the result of the bending strength test of both densities of LFC with different weight fractions of ramie fibre. The bending strength rose markedly from the control specimen (0.00 % ramie fibre) up to the addition of 0.60 % of ramie fibre weight fraction as shown in Figure 7 for entire testing ages. The improvement in the bending strength of the LFC was credited to the fact that ramie fibre acts as a strengthening layer that ties the lattice of the cementitious matrix in a durable way relative to the specimen. Meanwhile, the bending strength declined when 0.80 % of ramie fibre was added to LFC. The reason for the reduction in the bending strength was the interruption of fibre presence. Next, the highest bending strength was logged on day-56, compared to day-7 and day-28. The highest flexural strength was 0.50 N/mm^2 at day-56 with the addition of 0.6 % of ramie fibre. The lowest flexural strength was 0.20 N/mm^2 without any fibre addition on day-7. It can be seen that plain LFC achieved a lower bending strength compared to the LFC with the addition of ramie fibre. The reason for the increase in bending strength was the fracture process of the fibre, which was derived from the progressive debonding of the fibre that slowed the transmission of a crack in the LFC matrix. The bending strength of LFC is between 18-30 % of its compressive strength. The existence of ramie fibre in LFC is to strengthen LFC mass and transfer the basic material character from brittle to ductile elastic-plastic [22]. Ramie fibre promotes enhancing the bending strength of LFC. Yet, an excessive amount of ramie fibre in the cementitious matrix will lead to reducing bonding and deterioration of stable foam [23]. The use of a 0.6 % volume fraction of ramie fibre can be considered an optimal percentage for LFC based on the increment of bending strength recorded in this investigation. The augmentation of bending strength is consistent with the compressive strength rise [24].

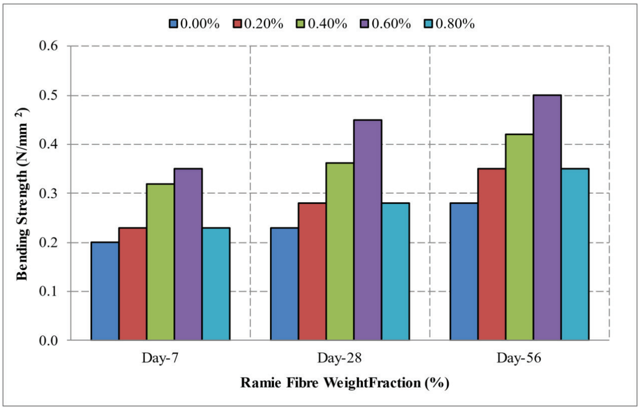

Figure 7: Bending strength of LFC with different volume fractions of ramie fibre

Compressive strength

Figure 8 shows the experimental results of the compressive strength of LFC with different weight fractions of ramie fibre. It can be seen from these figures that adding ramie fibre into LFC had improved the compressive strength no matter what the weight fraction was. Testing at 7, 28, and 56 days of curing demonstrated that overall, the mixes resulted in enhanced compressive strength compared to the control sample (no addition of ramie fibre). The optimum volume fraction of ramie fibre was 0.6 %. The highest compressive strength achieved on day 56 was 1.69 N/mm^2 with the inclusion of 0.6 % weight fraction of ramie fibre compared to the control sample which only had a compressive strength of 1.24 N/mm^2.

Beyond the optimum level of ramie fibre, agglomeration and the non-uniformity dispersion of fibre were seen, which results in a drop of compressive strength (at 0.8 % weight fraction of ramie fibre). A high amount of ramie fibre in LFC will retard the process of hydration hence leading to low compressive strength. As LFC comprises void gaps of a wide range of sizes and shapes in the LFC matrix and micro-cracks at the transition zone between the matrix, the addition of ramie fibre will aid in the failure of the mode under compressive load [25].

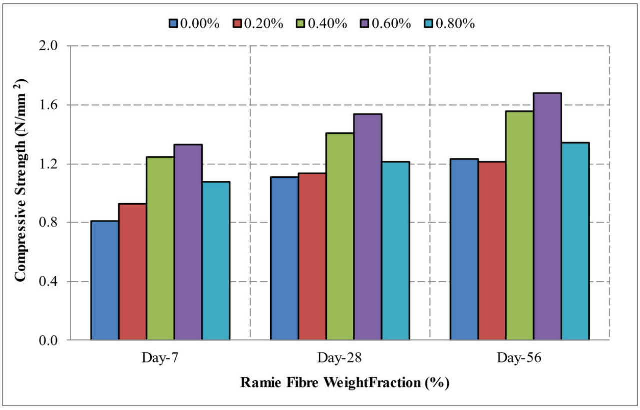

Figure 8: Compressive strength of LFC with different volume fractions of ramie fibre

CONCLUSION

The following conclusions can be withdrawn from this research:

- Ramie fibre of 0.6 % was the optimum dosage in LFC that gave outstanding compressive strength, flexural strength and splitting tensile strength.
- Addition of ramie fibre in the LFC cementitious matrix helped in preventing the propagation of micro-crack in the plastic state of LFC when the load was applied.
- Ramie fibre poses a high failure strain which can give superior compatibility between the fibres and the LFC cement matrix.
- Ramie fibre reacts as an aggregate that gives the denser structure of the microstructure, which reduces the size of the voids, thus refining the arrangement of the pores.

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