Comparative Study on Strength of Foamed Concrete Consisting Hybrid Fiber

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Abstract. This paper presents the performance of foamed concrete (FC) with two additives, namely coir fiber (CF) and steel fibers (SF), which can be categorized as hybrid fiber materials that are environmentally friendly because one of the fibers is an agricultural waste. In addition, it can also increase the foamed concrete strength. The CF was added in the FC mixture in three different percentages; namely 0.5\%, 1\% and 1.5\% with fixed SF percentage at 3\% for each mixture. The FC-CF-SF mixtures were tested in the laboratory to determine its fresh properties and mechanical properties. From the findings it showed that the workability of foamed concrete reduced when the hybrid fiber increased. The result presents the highest value of compressive strength was 21.9MPa obtained on FC-CF-SF with percentage of 1\% CF and 3\% SF at 28 days. For tensile strength, the highest value obtained from the test on cylinder specimen at 28 days was 1.94MPa with FC-CF-SF added with 0.5\% CF and 3\% SF. Meanwhile, the maximum value of flexural strength achieved was 3.4MPa obtained on FC-CF-SF added with 1\% of CF and 3\% of SF and the highest ultimate load recorded was 8.27MPa obtained on FC-CF-SF added with 1\% of CF and 3\% of SF content. Based on the observation, the foamed concrete consisting hybrid fiber experienced less crack compared to control specimen.

1. Introduction
In construction industry, the major construction material used is concrete. Along with the developments of technology, concrete has been utilized to build structures, includes small and large structures. Hence, there are high demand for concrete every day because it has become the most popular materials used in industrial construction. Concrete also plays an important role in increasing the popularity due to its durability and availability. Cement and aggregates combined to form concrete or also defines as composite materials. Examples of aggregates are sand, fine and coarse grinding. Concrete has characteristics of low maintenance, fire resistance and long life, thus, lead to an increase in the use of concrete. Even so, concrete has low strength to weight ratio which lead to the main constraint of concrete. Normal concrete has density of 2200 kg/m\textsuperscript{3} up to 2600 kg/m\textsuperscript{3} \cite{1}, therefore, the structure supports the high density concrete self-weight too.

The classification of lightweight concrete lies between density ranging from 400 kg/m\textsuperscript{3} to 1850 kg/m\textsuperscript{3}. Lightweight foamed concrete (FC) or defined as light cellular concrete is a type of lightweight concrete and it is built up by including foam agents into the mortar in the form of air-voids. A combination of sand sized of 4.75 μm, water, foam and Portland cement produces foamed concrete
which also uses foam generator to dilute foam agents into water. Due to its easy production, foamed concrete is seen as a potential solution to economic problems which comprises lightweight construction with larger scale including structural members, partitions, filling grades and road embankment infilling. Axel Eriksson invent foamed concrete and it was built in the early 1920s. The first foamed concrete used Portland cement as its base [2]. According to Sach and Seifert [3], the assembly of foamed concrete was limited and Linde described its production, properties and application.

In this research, hybrid fiber will be applied which is consisting of two type of fiber; namely, coir fiber (CF) and steel fiber (SF) [4] as a filler in the mixture of foamed concrete where it can be categorized as Green Foamed Concrete (GFC). An organic coconut extract a fiber named coir fiber from the external shell with length of 0.3 mm to 250 mm with average length of 100 mm to 200 mm. Coir fiber has physical characteristics of stiff and tough because the lignin volume is higher than other natural fiber [5]. The husk contain ground tissue which is made from pectin and hemicelluloses [6]. Coir fiber has low cellulose content but high in lignin content. High lignin content produce stiff, stable, aerial, biodegradable and renewable fiber. Pectin present virtually in all plants because it helps in the formation of the cell structure due to its high-molecular-weight carbohydrate polymer.

The other fiber that will be used in this study is steel fiber which can be specified in terms of its length, diameter, configuration, tensile strength and aspect ratio [7]. Steel fiber can boost the compressive strength up to 25%. Even though the member contain reinforcement bars, the presence of steel fiber has no effect to the compressive strength. Tensile strength can be increased by positioning the fiber in same direction with the stress. Uniform fibers resulted in small strength increases in range 0% to 60%. Therefore, it is not effective to increase tensile strength alone with the purpose of using steel fibers [8]. Bending strength will received higher impact compared to compressive strength when utilizing steel fibers. Bending strength has increased 100% with the addition of steel fibers and thus, bending is directly proportional to the fiber content [9].

2. Materials and Methods

2.1. Materials

Cement act as a binder in foamed concrete and it was mixed together with sand, water and foaming agent. Foaming agent is used to create foam while coir fiber and steel fiber were used as filler in the mixture at a specific percentages. The experimental works are divided into three (3) phases; which are materials preparation, foamed concrete fabrication added with coir fiber and steel fiber and specimens testing phase. Figure 1 shows Portland cement and foaming agent used in this study.

![Figure 1. Portland cement and foaming agent](image)

In this research, hybrid fiber are used with two different types of fiber, which are coir fiber and steel fiber. These fibers act as additional material in the foamed concrete mixture. Coir fiber and steel fiber were shown in Figure 2 and Figure 3, respectively. The introduction of utilization of agro-waste and steel fiber in this research is to achieve the objectives of this research. The experimental works had been done by casting the foamed concrete specimen consisting of 0%, 0.5%, 1%, and 1.5% of CF and 3% of SF into the cement content in each mixture.
2.2. Methods
Compressive strength test was done at 7 and 28 days after curing process. Twelves (12) cubes were prepared and left for curing for 7 days and another twelves (12) cubes for 28 days of curing process. In total, twenty-four (24) cubes of different foamed concrete mixture had been tested on compressive strength. Meanwhile, tensile strength had been tested on eight (8) cylinders with different percentages of CF and SF added in the foamed concrete mixture. Each two-cylinder made of foamed concrete with different percentages of CF which are 0%, 0.5%, 1% and 1.5%. The percentage of SF used for each mixture was fixed at 3% of cement content. Six (6) prisms were prepared and tested with four-point bending test which consist of control specimen, 3% of SF and 1% of CF + 3% of SF. The design mix proportion of foamed concrete in this study were based on the previous research on mixture ratio and was shown in Table 1.

Table 1: Mixture ratio for foamed concrete with density 1800kg/m³

| Material | Sand to cement | Water to cement | Foam to cement |
|----------|----------------|-----------------|----------------|
| Ratio    | 2:1            | 0.5             | 0.9            |

Fresh state properties test was conducted on FC-CF-SF according to ASTM C 1621/C 1621M-09b [10]. The workability of foamed concrete was determined using the J-ring test. J-ring test is method which is used to determine the passing ability of foamed concrete combined with slump cone mould. The flow spread and blocking step are the two parameters determined using the J-ring test. Table 2 shows the types of blocking assessment that indicated from difference between slump flow and J-ring test.
The compressive strength test is the main test that was tested by compressive test according to BS EN 12390-3:2009 [11]. This test was done on the foamed concrete cubes with dimension of 100 mm x 100 mm x 100 mm which were undergone curing process of 7 and 28 days. The average of three specimens were evaluated to obtain the compressive strength value. The cube samples were placed at the centre of testing machine, on the plate, to proceed the test with the aid of the universal testing machine (UTM). Figure 4 shows the compressive strength test.

Split tensile strength testing was a fundamental test which a specimen subjected to a control tension until the specimen shown a failure. The equipment used for tensile strength test was same as compression test which is Universal Testing Machine (UTM) according to BS EN 123906:2006 [12]. The specimen was tested at 28 days to determine the tensile strength and the dimension of the cylinder is 100 mm for the diameter and 200mm for the height. The cylinder sample was horizontally placed in between steel holders in the testing machine. The ultimate load, crack pattern and flexural strength of normal foamed concrete and foamed concrete added with hybrid fibers were determined by conducting four point bending test. It exposes larger part of the prisms to the maximum stress by providing 4 bearings against foamed concrete under the central bearing. The specimen used for this test is prism where the dimensions of the prisms are 100mm x 100mm x 600 mm at 28 days of curing. Figure 5 shows the four point bending point test.

### Table 2. Types of blocking assessment

| Difference between slump flow and J-ring flow | Blocking assessment       |
|---------------------------------------------|---------------------------|
| 0 to 25 mm                                   | No visible blocking       |
| 25 to 50 mm                                  | Minimal to noticeable blocking |
| > 50 mm                                     | Noticeable to extreme blocking |

![Figure 4. Compressive strength test](image)

![Figure 5. Four-point bending test](image)
3. Results and discussions
The outcomes recorded from the experimental works are analysed and discussed in this section. From the test conducted, the fresh state and mechanical properties of foamed concrete were obtained. This result was used to clarify the workability and durability properties of FC incorporating with CF and SF. The hardened properties of FC incorporating CF and SF were investigated which include compressive strength, tensile strength, and flexure strength.

3.1. Fresh state properties of FC-CF-SF
The fresh state properties of foamed concrete mixed with CF and SF include flow ability.

3.1.1. Flow ability
For flow ability study, the workability of foamed concrete incorporated with different percentages of CF and SF in the mixture was determined by conducting J-ring test (slump flow test). The result of J-ring test in accordance to ASTM C 1621 / C 1621M [10] was tabulated in Table 3. The results show that the performance criteria of flow ability were achieved with respect to slump flow requirement of ASTM C 1621 / C 1621M. According to the J-ring test of control specimen results, the workability indicated as good because it reached 11mm. When there was a percentage increase to 1.5% of CF and 3% of SF in the foamed concrete mixture, the workability decrease to 24mm. This is because, a lot of foaming liquids required when the foamed concrete was mixed with hybrid fibers. This causes the interference of foam workability. As a result, the outcomes of J-ring test obtained within 0 mm until 25 mm only which determines the workability of FC-CF-SF is in the unobtrusive category where there is no visible blocking conforms to the prescribed standards.

| Mix       | Slump flow (mm) | J-ring flow (mm) | Difference between slump and J-ring flow | Type of blocking |
|-----------|----------------|------------------|----------------------------------------|-----------------|
|           | d1  | d2  | d1 + d2 | d1 | d2  | d1 + d2 |                                |                 |
| Control   | 534 | 529 | 531     | 519 | 521 | 520     | 11                                | No blocking     |
| 3% SF     | 431 | 427 | 429     | 426 | 398 | 413     | 16                                | No blocking     |
| 3% SF 0.5% CF | 433 | 397 | 414     | 402 | 387 | 393     | 21                                | No blocking     |
| 3% SF 1% CF | 408 | 392 | 399     | 382 | 380 | 381     | 22                                | No blocking     |
| 3% SF 1.5% CF | 437 | 391 | 413     | 401 | 377 | 389     | 24                                | No blocking     |

Where,
\( d1 \) is the largest diameter of flow spread in millimeter;
\( d2 \) is the flow spread at 90° to \( d1 \) in millimeter;

3.2. Mechanical properties
The mechanical properties presented in this section are compressive strength, tensile strength, and flexure strength.

3.2.1. Compressive strength.
Figure 6 presents the compressive strength for the control specimen was increased until 28 days where it reached 11.9MPa. The compressive strength of FC with added CF and SF increased as CF increased to 1% and SF fixed at 3%. However, the compressive strength was decreased when 1.5% of CF 3% of SF added in the foamed concrete mixture. From 7 days to 28 days, the value for compressive strength kept increasing in this study. The highest compressive strength value recorded were 19.4MPa and 21.9MPa which on 7 days and 28 days, respectively. It was observed that, the longer time it takes for curing process, the higher the compressive strength of foamed concrete achieved. The percentage of hybrid fibers added in the foamed concrete influenced the results of compressive strength recorded. This is because, water in foamed concrete was absorbed by CF and the voids were filled with SF. The gap between fine aggregate in the foamed concrete mixture filled by hybrid fibers.
3.2.2. Tensile strength

Figure 7 shows the results of tensile strength for control FC and FC-CF-SF with various percentages of CF at 28 days. The highest tensile strength was recorded at 1.94MPa in FC-CF-SF mixture with 0.5% CF and 3% SF added. This is due to the coir fiber composition which are high in lignin, larger diameter and low cellulose content that leads coir fiber as a strong reinforcing agent. This resulted in strong bond created among particles in foamed concrete and allows it to absorb energy to withstand crack formation [13].

3.2.3. Flexure strength.

From Figure 8, the value of flexural strength shows increment when CF and SF added into the foamed concrete mixture. The highest value of flexural strength was 3.4MPa achieved by FC mixture contain 1% of CF and 3% of SF. Meanwhile, the lowest flexural strength recorded was 2.5MPa which achieved by control specimen. Obviously, the addition of hybrid fibers has increased the flexural strength of foamed concrete. This is due to concrete bridges which was developed by the fibers added into the mixture. The fibers help to control the crack propagation by filling the air voids in the FC mixture. Besides the increase in flexural strength, the addition of fibers also increase the ultimate load of FC. The ultimate load recorded were 5.8kN, 6.68kN, and 8.27kN for control specimen, FC added with 3% of SF and FC added with 1% of CF and 3% of SF, respectively.
Figure 8. Flexural strength and ultimate load of FC with different mixture

Based on Table 4, flexural crack occurred at mid-span of all prisms. Control specimen fractured into two parts at the ultimate load zone as it undergone extreme crack propagation. The crack produced at control specimen was observed to be the largest crack width of all among the prisms. The specimen contained 3% of SF managed to not split into two parts and it resulted in less crack propagation rather than control specimen. However, specimen contained 1% of CF and 3% of SF produced the smallest crack propagation and crack width of the prism. Based on the results, foamed concrete added with hybrid fiber has been proven to control the propagation of crack.

Table 4. The crack pattern of foamed concrete

| Physical observation | Specimen |
|----------------------|----------|
|                      | Control  |
|                      | 3% SF    |
|                      | 1% CF + 3% SF |

4. Conclusions
The conclusions from this study are:

- The results of foamed concrete workability obtained from slump flow test and J-ring test determined its fresh state properties. Based on that, there is a decline for fresh foamed concrete results when there is increment in percentage of hybrid fiber. Despite that, the whole workability outcomes resulted in stable mixture for foamed concrete.
- The highest value of compressive strength was 21.9MPa obtained on FC-CF-SF with the percentage of 1% CF and 3% SF at 28 days.
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