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ENGINEERING PROPERTIES OF FOAMED CONCRETE REINFORCED WITH SUSTAINABLE BAMBOO FIBRE

The consumption of foamed concrete (FC) in conjunction with the incorporation of natural fibre is recognized as an outstanding effort in promoting sustainable practices. This effort is aimed at reducing greenhouse gas emissions and the impact it leaves behind on the environment. The goal of this experiment is to discover the viability of incorporating raw bamboo fibre (BF) into the fabrication of 1000 kg/m^{3}density FC. The shrinkage, flexural, compressive, and tensile strengths of the material were the four characteristics that were considered throughout the analysis. The weight fractions of BF that were utilized were 0.0%, 0.1%, 0.2%, 0.3%, and 0.4% respectively. According to the results, the FC-BF composites' drying shrinkage, compressive, flexural, and tensile strengths were best achieved when 0.3% BF was present. This was caused by the BF's adhesion to the cementitious matrix of the FC. Additionally, BF functioned as an anti-micro crack that prevented FC from developing internally induced microcracks and cracks.

Keywords: Foamed concrete; bamboo fibre; mechanical properties; flexural; compression

1. Introduction

The construction sector is a significant contributor to energy consumption, representing a considerable proportion of overall energy usage. Additionally, it plays a key role in driving economic growth within a country [1-4]. The industry in question has been subject to criticism because of its role in exacerbating global warming and imposing significant environmental burdens, including excessive water consumption, contamination, and depletion of natural assets [5-7]. Actions such as fuel incineration, drilling and hauling are identified as the main contributors to carbon dioxide (CO_2) emissions and their negative impacts on human health [8]. In light of escalating environmental apprehensions, the building sector has commenced adopting sustainable methodologies with the aim of reducing resource consumption and alleviating ecological repercussions [9]. Sustainable solutions are based on designing buildings, building methods, and building materials in a way that makes the best use of resources [10]. The acquisition of construction materials from renewable and recycled sources is a crucial aspect of constructing sustainable buildings [11,12].

Conventional construction materials possess a significant energy matter and require substantial energy consumption during their recycling process [13,14]. In contrast, materials such as wood and bamboo are widely acknowledged as renewable and sustainable choices for building owing to their multitude of advantageous characteristics, which include low embodied energy and little carbon footprint. By implementing effective management strategies and adopting sustainable harvesting practises, it is possible to maintain a perpetual supply of wood and bamboo-derived goods [15]. This approach can contribute to meeting the requirements of green buildings [16-18].

Foamed concrete (FC) is a prominent construction material that enables the development and implementation of lightweight structures [19-21]. The removal of coarse components from LWFC mixtures allows to produce mixtures that are highly malleable [22]. The FC exhibits a significant degree of fluidity, which is attained through the amalgamation of a mortar slurry containing cement with pre-made foam [23-25]. The utilisation of specific combinations of materials can offer notable benefits in construction projects located in areas with challenging soil conditions, where the load exerted on building foundations

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tends to be relatively low [26-28]. Nevertheless, the growth of FC technology may face obstacles due to environmental degradation resulting from the release of harmful substances and concerns about sustainability arising from the extraction of natural aggregates [29]. The application of natural fibres in the enhancement of properties of low-fluorinated compounds during the production of concrete has resulted in a significant range of potential outcomes [30].

It is crucial to acknowledge that FC has faced various obstacles in its progression as a material for building construction. These challenges include brittleness, reduced bending and tensile strengths, elevated drying shrinkage, increased water absorption capacity, and limited fracture control capabilities. Furthermore, the problem of brittleness has been identified as a significant concern [31]. The utilization of FC is restricted to non-load-bearing purposes due to its limited strength and durability [32]. The concerns associated with the low fracture toughness of FC are mitigated when the material is reinforced with polymer fibres obtained from diverse sources [33]. The uniform dispersion of both natural and synthetic fibres within a fibre composite can lead to a substantial enhancement in the strength of a previously weak matrix [34]. As a result of this phenomenon, FC exhibits behaviour that resembles that of a composite material rather than an unreinforced FC [35].

In recent years, the adoption of environmentally sustainable practices within the building industry has emerged as a significant concern in Malaysia [36]. The Malaysian government has implemented several initiatives aimed at encouraging participants in the construction activity to incorporate green building practices [37]. The primary objective of green building is to mitigate carbon footprint and minimize gas emissions. In order to promote sustainable building practices within the built environment, it is imperative for all stakeholders in Malaysia to meet the stipulated criteria of the Green Building Index (GBI) [38]. This would not only enhance the level of consciousness among construction participants but also foster a supportive atmosphere for sustainable construction endeavours [39]. Furthermore, there has been a significant increase in global interest about environmentally sustainable construction, leading to extensive research efforts on the subject of green concrete on a global scale. Hence, the employment of natural fibre in the production of concrete within the context of FC can serve as a viable solution to address the aforementioned issues [40]. The utilization of FC in construction has several benefits. These include the provision of effective thermal insulation, enhanced fire resistance, reduced weight, and decreased usage of certain elements in the concrete mixture, such as cement, fine particles, stable foam, and water. Natural fibres have numerous advantages in comparison to synthetic fibres, such as their biodegradability, low density, and resistance to melting under elevated temperatures. The utilisation of natural fibres in the reinforcement of cementitious materials has been observed to be particularly advantageous in the development and fabrication of construction materials. Bamboo, banana, coir, cane, and henequen represent several natural fibres [41]. Natural fibres are extensively utilised in the manufacturing of lightweight concrete due to their superior environmental sustainability and cost-effectiveness in the construction industry compared to synthetic fibres. Hence, the principal objective of this exploration focuses on assessing the feasibility of utilizing unprocessed bamboo fibre (BF) as a means to enhance the mechanical characteristics of FC. BF is a resilient and robust natural fibre that has notable tensile strength, making it a viable material for integration inside concrete composites.

2. Materials and methods

2.1. Materials

Cement, sand, foam and water are the primary materials employed to make FC. Portland cement according to British Standard BS-12 was used and a handy foam generator was utilized to generate the foam. A synthetic surfactant was utilized to produce the foam. Also, fine sand was used. The proper size of the fine aggregate applied was 1.18 mm and was sieved with a sieve machine in accordance with BS-882. Tap water which was free from impurities was used. The water-to-cement ratio was set at 0.45. The BF used in this study was collected from a local farm and processed into 17 mm BF by a mechanical refining process. Fig. 1 displays the BF employed in this study. The percentage by weight of BF used was 0.0%, 0.1%, 0.2%, 0.3% and 0.4% of the total volume of the blend, respectively. TABLES 1

Fig. 1. Processed BF of 17 mm in length

TABLE 1

Physical and mechanical properties of bamboo fibre

Element	Properties
Diameter	24.6 um
Density	0.65 g/cm^3
Length	20 mm
Shrinkage coefficient	0.664
Element	Properties
Tensile strength	205.5 MPa

TABLE 2

Chemical composition of bamboo fibre

Composition	Percentage
Hemicellulose	23.1
Cellulose	48.6
Lignin	25.5
Extractives	2.8

and 2 demonstrate the physical and mechanical properties, and chemical constitution of the BF, respectively.

2.2. Mix Design

In order to conduct the experiment in the current study, a total of five combinations were produced. TABLE 3 displays the proportions of the mixture design characterized by a density of 550 kg/m^3. In this study, the utilization of BF as an addition was investigated at several concentrations, specifically 0.1%, 0.2%, 0.3%, and 0.4% by volume of the total mixture. As previously stated, the composition of the mortar comprised cement, sand, and water at a ratio of 1:1.5:0.45. Once homogenous FC mix was attained, bamboo fibre was added to the base mix as per shown in Fig. 2.

TABLE 3

Mix design proportion

Specimen	Density (kg/m^3)	Bamboo fibre (kg)	Binder (kg)	Filler (kg)	Water (kg)
Control	1000	0.000	18.73	28.10	8.43
0.1%BF	1000	0.057	18.73	28.10	8.43
0.2%BF	1000	0.114	18.73	28.10	8.43
0.3%BF	1000	0.170	18.73	28.10	8.43
0.4%BF	1000	0.227	18.73	28.10	8.43

2.3. Experimental Setup

2.3.1. Compression test

The experiment was conducted utilizing a comprehensive testing device having a utmost load ability of 300 kilonewtons. The test conducted adheres to the standard BS12390-3 and involves the utilization of a cubic sample of 100×100×100 mm (Fig. 3). The outcome was acquired, and the test was performed on the 7, 28 and 56 day.

2.3.2. Bending test

The FC bending strength was assessed using a rectangular beam with dimensions of 100×100×500 mm (Fig. 4). The examination was conducted in accordance with ASTM C348. This test program was made possible by the universal testing device. The tests were conducted on the 7th, 28th, and 56th day.

Fig. 2. Inclusion of BF in FC base mix

Fig. 3. Compression test setup

Fig. 4. Four point flexural test setup

2.3.3. Splitting tensile test

The split tensile strength test was performed using the guidelines specified in ASTM C496/C496M. The specimens have a diameter of 100 mm and a height of 200 mm (Fig. 5). The experiment was carried out on the 7th, 28th, and 56th day.

Fig. 5. Split tensile test setup

3. Results and discussion

3.1. Compressive strength

Fig. 6 depicts the outcomes of the compression strength analysis conducted on FC samples that were reinforced with varying weight percentages of BF. The findings indicate a progressive rise in BF within the FC. The compressive strength of the specimens reached its maximum value of 4.04 N/mm^2 on day-56 when including 0.3% BF. Conversely, the control mix exhibited the lowest compressive strength of 2.46 N/mm^2 on day-7. In addition, it is seen that the compressive strength value at the end of the seventh day exhibited marginal improvements, rising from 2.46 N/mm^2 in the control mixture to 3.15 N/mm^2 when using 0.3% BF. Subsequently, there was a decline observed in the value, which reduced to 2.53 N/mm^2, representing a fall of 0.4% in relation to the initial value of BF in FC. On the 28th day, the compressive strength of the concrete mixture increased from 2.86 N/mm^2 in the control mix to 3.59 N/mm^2 with the addition of 0.3% BF. However, it subsequently decreased to 3.00 N/mm^2 when the BF content was increased to 0.4%. The findings also indicate a progressive rise in compressive strength on day-56, commencing at 3.22 N/mm^2 for the control mix and reaching 4.04 N/mm^2 with a 0.3% inclusion of BF. However, the compressive strength begins to decline at 3.50 N/mm^2 with a 0.4% inclusion of BF. The compressive strength of FC is found to be lower based on the results obtained from the control mix. The compressive strength of the FC increases with longer testing durations, as evidenced by the contrast between the results obtained on day 7 and day 56, as depicted in the graph. The weakness identified can be addressed by incorporating a bonding agent, such as BF, into the system [42]. The inclusion of BF will effectively manage the crack formation on the FC and enhance the interfacial bonding between the matrix materials [43].

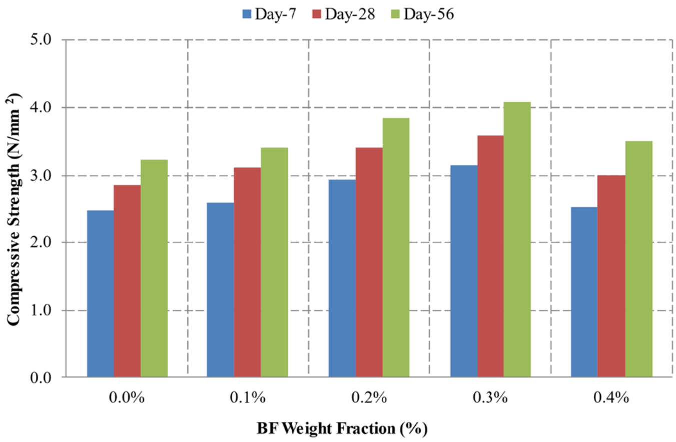

Fig. 6. FC compressive strength

3.2. Bending strength

Fig. 7 displays the FC bending strength at different amounts of BF. The figure illustrates the findings, indicating that the flexural strength reached its peak at 1.20 N/mm^2 on day-56 when including 0.3% BF. In contrast, the control mixture specimen demonstrated a weakest bending strength of 0.57 N/mm^2 on the seventh day. The bending strength exhibited an increase from 0.57 N/mm^2 in the control mix to 0.90 N/mm^2 with the addition of 0.3% BF on day-7. However, the bending strength began to decline when the BF concentration was increased to 0.4%, resulting in a value of 0.63 N/mm^2. Furthermore, the experimental findings indicate a noticeable increase in the values of 0.77 to 0.91 N/mm^2 and 0.84 to 0.98 N/mm^2 on day-28 and day-56, respectively, when incorporating 0.1% and 0.2% BF in comparison to the control specimen. Nevertheless, the FC with

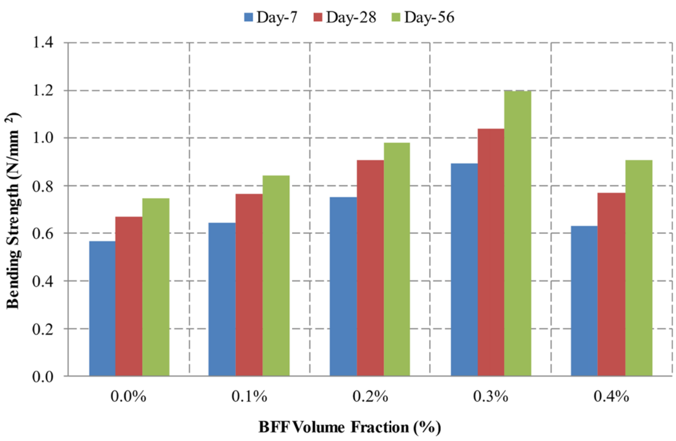

Fig. 7. FC bending strength

a body fat percentage of 0.4% experienced a drop in strength to 0.77 and 0.91 N/mm^2 on day 28 and day 56, respectively. This phenomenon can be attributed to a potential failure of the BF mechanism to adequately populate the matrix. The lower ratio of bending to compressive strength in FC, which typically falls within the range of 0.2 to 0.4, contrasts with that of conventional concrete [44]. However, the incorporation of BF has ensued in strength enhancement due to its ability to alter the material's brittleness.

3.3. Splitting tensile strength

Fig. 8 depicts the splitting tensile strength of FC specimens, wherein different weight percentages of BF were integrated. The maximum recorded splitting tensile strength value of 0.85 N/mm^2, with a 0.3% BF content, was found on day-56. Conversely, the lowest measurement of splitting tensile strength, 0.35 N/mm^2, was recorded on day-7 with the control specimen. The inclusion of BF in the FC leads to a significant improvement in the tensile strength under splitting conditions. Specifically, the splitting tensile strength improves from 0.35 N/mm^2 to 0.40 N/mm^2 after 7 days. The trend observed exhibits consistency between day-28 and day-56, as there is a notable increase in values from 0.41 N/mm^2 to 0.48 N/mm^2 and from 0.48 N/mm^2 to 0.55 N/mm^2, respectively. However, a discernible decline in the recorded measurements can be observed as the testing procedure advances, with values of 0.14 N/mm^2, 0.22 N/mm^2, and 0.26 N/mm^2 recorded on each sequential day of testing. The previously indicated case exhibited similarities in terms of both compressive strength and bending strength. Nevertheless, the integration of BF into FC acted as a unifying element that improved the coherence of the material structure, thus resulting in an augmentation of the strength [45,46].

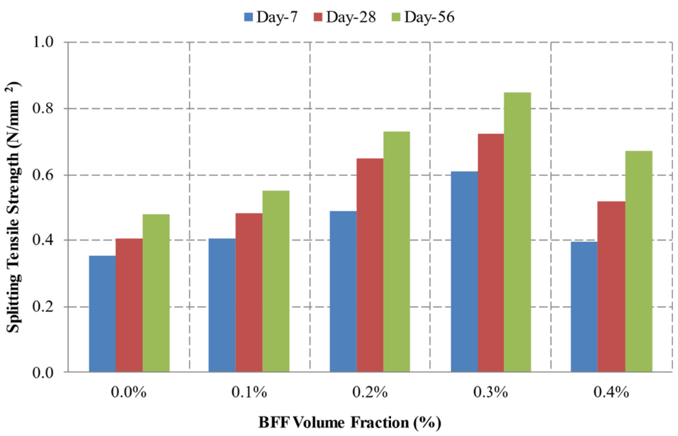

Fig. 8. FC splitting tensile strength

4. Conclusions

The present study involved conducting experimental research to investigate the strength properties of FC when reinforced with different weight fractions of BF. The FC used in the study had a density of 1000 kg/m^3. Five distinct weight fractions of BF were incorporated specifically 0.0%, 0.1%, 0.2%, 0.3%, and 0.4%. Based on the findings obtained in this experimental study, it can be concluded that the incorporation of BF material led to an improvement in the compressive, bending, and tensile strengths of FC. However, the varying weight percentages of BF included in the FC yielded distinct outcomes in terms of the mechanical properties of the composite. In general, it was observed that a volume fraction of 0.3% of BF in FC exhibited exceptional mechanical properties in terms of bending, compressive, and splitting tensile strengths, surpassing those of other volume fractions of BF. The employment of BF-matrix boundary bonding, characterized by a somewhat coarse surface, offers advantages due to its surface roughness. Consequently, the inclusion of BF fibre and matrix mechanically interlinked contributes to the augmentation of the mechanical characteristics of FC.

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