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Application of treated sugarcane bagasse fiber in lightweight foamed concrete composites and its influence on strength properties and thermal conductivity

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Abstract

The construction industry recognizes the need for green, lightweight, and self-compacting materials that are also ecologically benign. Recent studies suggest that the novel lightweight foamed concrete (LFC) could potentially reduce the self-weight of structures. Adding natural fibers to FC improves its mechanical properties and contributes significantly to sustainability. One of the greatest difficulties in constructing reinforced LFC is the reinforcing steel bars' corrosion, which impacts the behavior and lifetime structural integrity of concrete buildings. Therefore, this research aims to investigate the potential use of sugarcane bagasse fiber (SBF) in low-density LFC, after altering it with sodium hydroxide-based alkali treatment (NaOH) to enhance its properties. Low-density FCs are prone to serious durability and performance degradation; hence, in this experiment, FCs with a low density of 800 kg/m^3 were fabricated and evaluated. Quantification and evaluation were conducted on several different characteristics, including the slump, density, thermal conductivity, and compressive, flexural, and splitting tensile strengths. The findings suggest that employing SBF with an optimal reinforcing range of 3% to 4% can improve the mechanical characteristics and thermal conductivity of LFC-SBF composites. The slump flow gradually decreased from 1% to 5% of the SBF's weight fraction. The lowest slump flow was achieved by adding SBF to the LFC mixture at a weight fraction of 5%. The addition of SBF to LFC resulted in a significant boost in the material's splitting tensile, compressive, and flexural strengths. By adding 4% SBF to LFC, the optimal strength properties were concluded in the material. In addition to this, the weight percent of SBF contributed to an increase in the thermal conductivity of LFC. This was because the porous structure of LFC, which contained SBF, enabled it to absorb heat.

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Introduction

The current concern of society at large is the threat posed by climate change. Implementing energy-efficient materials is crucial in building to minimize energy use.[1] Experts specializing in sustainable building projected that the building and construction industries will generate over 40 billion tons of greenhouse gas emissions by the year 2030.[2] Bioclimatic concept incorporates specific requirements in construction to effectively minimize energy use and mitigate the release of pollutants into the surrounding environment. The thermophysical properties of building materials play a crucial role in reducing heat transfer through conduction and radiation, as well as achieving optimal insulation and energy efficiency. Implementing this method is one of the most direct approaches to substantially decrease emissions and can result in a reduction of up to 30% in the use of energy.[3] Thermal inertia element is an essential thermophysical characteristic required for regions that experience substantial temperature fluctuations between sunrise and sunset. Thermal inertia is a measure of a material's capability to transfer and retain heat, which is influenced by its thermal conductivity, thermal diffusivity, and volumetric specific heat capacity. Conversely, the movement of heat within the building is dependent on the rate at which the indoor temperature aligns with the outdoor temperature. Scholars are exploring the development of composite materials that incorporate natural fibers, which exhibit thermal latency when coupled with thermal inertia.[4]

By modifying the outermost layer of sugarcane bagasse fiber (SBF), it is possible to enhance interfaces connections while considering ecological factors and creating useful elements from recyclable materials.[5] Researchers have also examined the thermal conductivity of SBF as a form of insulation.[6] The findings indicated that the thermal conductivity was 0.046 w/mK within the temperature range of 15–32°C. Aminudin et al.[7] conducted a study on enhancing cement bricks by including SBF, which resulted in a 10% increase in weight. This modification led to a reduction in the heat conductivity to 0.62 w/mK. Several studies demonstrated that the chemical makeup of SBF can be influenced by factors including the age of SBF, process of gathering, and prevailing atmospheric conditions. These factors can impact the levels of cellulose, hemicellulose, lignin, and ash in SBF.[8]

The utilization of plant fibers in cement-based materials to enhance robustness, resilience, and ductility in areas that have seen cracking has experienced significant expansion.[9] The failure and decay of concrete structural elements rely primarily on the growth of cracks at either the macro or micro level due to external forces or external variables.[10] Thermal and humidity fluctuations in cementitious matrix result in the creation of tiny cracks that primarily occur on the outermost layer of aggregate. Furthermore, higher loads and ecological concerns contribute to a greater occurrence of micro-cracks in concrete. The use of various plant fibers is a noticeable influence in the formation of cracks and in enhancing the ability of concrete to absorb energy and withstand stress. This can reduce the risk of collapse in concrete structures, particularly in areas subject to repeated or seismic stresses.[11] Utilizing plant fibers is crucial in reducing crumbling, distortion, and thermal cracking by substituting thermal reinforcing. Moreover, the inclusion of other cementitious substances like rice hush ash, silica fume and fly ash, along with the variables of the form, dimension, category, quantity, and scattering arrangement of fibers, considerably impact the technical capabilities and economic effectiveness of concrete.[12,13] A diverse range of fibers with different mechanical, morphological, and chemical characteristics are employed for strengthening cementitious matrices.

Concrete is the most renowned building material used for construction applications. As compared to other construction materials, normal-weight concrete offers several advantages, including excellent mechanical qualities, low water absorption capacity, and great durability.[14,15] In terms of material properties, concrete's thermal performance is insufficient to utilize it merely as a building envelope.[16] Other insulating materials must be considered when constructing concrete parts to minimize the heat conductivity, especially the building envelopes.[16] Lightweight foamed concrete (LFC), which has a dry density in the range of 850–1950 kg/m^3,[17] is one form of building material noted for its advantageous thermal performance and sound absorption capacity.[18,19] Below this range, concrete is considered a non-structural material. Modern LFC manufacturing technology has been known for over a century, and it has grown significantly in the past 20 years.[20–22] This is due to the development of synthetic aggregates, innovative admixtures and additives, improved testing approaches, and substantial enhancements in production processes.[23] They enable the creation of sophisticated lightweight cementitious composites with improved durability and mechanical qualities, allowing them to be used for structural applications despite their low density.[24–26]

The advancement and application of LFC in the construction industry have been stifled by a number of shortcomings, the most significant of which are instability, fragility, inferior flexural and tensile strengths, extreme drying shrinkage, and high sorptivity.[27–29] However, despite these drawbacks, LFC has been increasingly utilized in recent years. In addition, there has been a significant amount of worry about its brittleness.[30,31] Since LFC does not possess suitable strength qualities, its usage is restricted to applications that do not require load-bearing functions.[32,33] When the material is reinforced by polymer fibers produced from a range of diverse sources, concerns connected to LFC's poor fracture toughness are addressed.[34–36]

LFC possesses numerous air gaps, which contribute to its advantageous properties, including being lightweight, highly fluid when poured, providing great thermal and sound insulation, good combustibility, and exceptional energy absorption ability. The extreme porosity and interconnection of the pores in LFC enable the infiltration of harmful elements, resulting in poor physico-mechanical properties and durability.[37] Bayraktar et al.[38] investigated the impact of cement dosage and waste tire rubber on the mechanical and abrasion properties of LFC. The rise in cement quantity led to an optimal augmentation of 205% in the compressive strength at a cement content of 500 kg/m^3, as opposed to the combination with an amount of 300 kg/m^3 at a foam content of 20 kg/m^3. The sorptivity readings fell when the amount of cement increased and the foam amount was lowered, regardless of the presence of silica fume. The combinations with cement quantities of 300 kg/m^3 and 500 kg/m^3 and foam content of 20 kg/m^3 achieved the lowest and highest shrinkage values of 5032×10^{-6} and 7065×10^{-6} mm/mm, respectively. The influence of the quantity of cement on the shrinkage of the mixes without silica fume was quite noticeable. Increasing the cement level from 300 to 500 kg/m^3 resulted in a major decrease of 29% in shrinkage, while maintaining a foam content of 20 kg/m^3. Gencel et al.[39] evaluated the possible use of expanded perlite and fine-sized waste glass sand as the primary components in LFC mixtures. The inclusion of expanded perlite enhances the insulation capabilities of LFC, possibly because of the greater porosity of expanded perlite in comparison to glass sand. The results of this study showed that leftover glass sand can be effectively employed to produce environmentally friendly insulating LFC.

When natural and synthetic fibers are uniformly distributed throughout LFC, the brittle matrix that is present in LFC is greatly reinforced.[40,41] Because of this, concrete starts to act more like a composite material, which has characteristics that are considerably different from those of unreinforced LFC.[42] In recent years, synthetic fibers have been the sort of fiber that has been used the most often to reinforce concrete; nevertheless, natural plant fibers are becoming an increasingly attractive alternative.[43,44] There has been a rise in concern regarding materials reinforced with natural plant fibers since it is possible to make materials with superior strength properties. This is because it is viable to develop materials with these features. Natural plant fibers are particularly important because they do not deplete natural resources and can be replenished.[45,46] These natural plant fibers might be utilized in lieu of synthetic fibers, which have a greater effect on environment than natural plant fibers do.

Many scientific studies on cement-based composites strengthened with natural fibers such as coconut, jute, flax, hemp, sisal, and leaf fibers have been done. These studies have illustrated, in a manner that is consistent with the results obtained when polymer fibers are employed as fortification, that fiber strengthening boosts the strength performances of cement-based compounds and enhances the tensile, flexural, impact, and compressive strengths.[47,48] Issues have been raised concerning the durability performances in long-term construction utilizing natural plant fibers in cement-based matrices since this might result in a loss of the material's strength and toughness.[49] These materials were created by combining natural plant fibers with cement. The alkalinity of the cementitious matrix is what sets off the process of deterioration of natural fibers as well as the concomitant loss in the elasticity and deformation capacity owing to embrittlement caused by mineralization. The degradation of hemicellulose and lignin is more pronounced in alkaline environments, leading to a gradual deterioration of the cell wall integrity and fiber stability in cement compounds.[50] The cell wall integrity and stability of fibers in cement compounds may deteriorate over time.

Bayraktar et al.[51] assessed the physical, mechanical, durability, and thermal characteristics of LFC reinforced with basalt fiber, which also contained waste marble powder and slag. The inclusion of basalt fiber and waste marble powder led to remarkable increases in the compressive and flexural strengths of LFC. Specifically, at 7 and 28 days, the compressive strength increased by 179.49% and 141.79%, respectively, while the flexural strength increased by 139.91% and 93.18%, respectively. Additionally, the LFC mix with a 2% basalt fiber content and 30% slag exhibited the least sorptivity, whereas the LFC mix with 0% basalt fiber and 30% slag had greatest sorptivity. Gencel et al.[52] explored the combined effect of basalt fiber and silica fume on properties of LFC. They found that the addition of greater amounts of basalt fiber and silica fume reduces the flowability of LFC, possibly because of the high surface area of silica fume and the limited dispersion of basalt fiber. An increased concentration of foaming agent, however, leads to enhanced flowability, presumably owing to a decrease in the volume of solids of LFC. The inclusion of silica fume and basalt fiber has a substantial impact on the compressive, flexural, and splitting tensile strengths of LFC. The incorporation of basalt fiber, ranging from 0% to 3%, led to a substantial improvement of approximately 88% in the flexural strength.

It is of the highest necessity to identify the weight fractions of the many components that are included inside the mixture, such as fibers, binder, filler, water, and surfactant. Natural fibers are better than synthetic fibers in a variety of ways, including their capacity to disintegrate organically, their low density, and their resistance to melting at high temperatures.[53] Natural fibers also have a lower risk of causing allergic reactions than synthetic fibers. Natural fibers, which are very important in the production and development of building materials, might lend a hand in fortifying cementitious materials. This can make cementitious materials more robust. Othuman Mydin et al.[40] conducted research on employing coir fiber in LFC. They revealed that the incorporation of coir fiber into LFC reduces the compound's heat conductivity and diffusivity while simultaneously increasing the heat capacity of the compounds.

Alkaline treatment, also known as mercerization, is a widely utilized and cost-effective method opposed to other treatments including acetylation and salinization.[54] This procedure is submerging plant fibers in a solution of sodium hydroxide (NaOH) in water, which modifies the hydrogen-bonded connections due to their interaction with an alkaline solution. As a result, the hydroxyl groups in the alkoxides experience ionization, that helps expose reactive OH- groups on the surface of the fiber, reducing its hydrophilicity.[55] Concurrently, this treatment breaks down specific quantities of lignin, pectin, hemicellulose, and waxy substances, which enhances the space between the fibers and creates a coarse texture on the surface of the fibers.[56] The presence of roughness on the surface creates mechanical anchor points, which strengthen the link between fibers and matrix. As a result, the mechanical properties of the composite material are improved by facilitating stress transmission and ensuring uniformity throughout the matrix.[57] Consistently, NaOH concentrations ranging from 2% to 5% have been often used among the regularly employed application strategies. An improved mechanical response of the fiber was obtained within this concentration range.[58] The presence of NaOH in concentrations greater than 5% did not enhance the fiber response, even when all contaminants were eliminated under these circumstances. This phenomenon may be linked to the development of a less robust, uneven, and more fibrillated surface of the fiber. Siddika et al.[59] made a chemical modification of jute and coconut fibers using different concentrations of NaOH (5% and 10%). They found that the composite made from fibers modified with 5% NaOH exhibited superior mechanical qualities compared to the composite made from fibers treated with 10% NaOH. Alkalinization often enhances the final strength of composites. For instance, Sedan et al.[60] reported that treating hemp fibers with a 6% NaOH solution caused degradation of hemicellulose in the fibers. This degradation resulted in increased roughness and stress transfer within the matrix, leading to a 40% increase in the modulus of rupture of the composite.

A limited amount of research has been done to establish the effects of adding SBF to concrete.[61] The findings illustrated that the employment of SBF boosted various strength properties of concrete. It was stated that adding SBF up to 0.5% to normal-strength concrete and lightweight concrete enhanced the compressive strength of the mixture.[62] Adding SBF to the soil blocks diminished the density of blocks, which can be ascribed to the low density of SBF, and it was also displayed that the water absorption capacity of the blocks raised considerably. Contrarily, the reinforced soil blocks had greater compressive and tensile strengths than the soil blocks that were unreinforced, and the maximum efficacy of the improvement was attained at a 0.5% weight fraction of SBF to the soil.[63] The use of SBF improved the bending and tensile strengths as well as the amount of impact engrossed energy when combined to the composite materials, according to recent studies that looked into the impact of SBF when utilized as reinforcement in the materials. Based on a study by Mangi et al.,[64] SBF can be used as a cement replacement (by approximately 1.5% by weight) in the production of cement bricks without altering the brick's characteristics. This can have an influence on both economy and environment. Therefore, this investigation attempts to explore the prospective utilization of treated SBF as an additive in LFC for mechanical properties and thermal conductivity improvements. Varying SBF weight fractions between 1% and 5% will be added to LFC, and several strength parameters and thermal performance will be assessed accordingly.

Materials and mix proportions

Materials

Entire LFC mixtures were made using ordinary Portland cement (OPC). According to the BS197-1 standards,[65] OPC has a strength grade of 53.6 N/mm^2 and a soundness of 12 mm. In this experiment, fine river sand provided by a regional supplier was utilized as a filler. The cohesiveness, high surface area, and gradation qualities of fine river sand are all factors in its selection as a workable LFC additive. Particles with decreasing size should become less workable as their surface area decreases. In addition, fine filler aids in compacting foamed concrete blends. Clean water was utilized for the mixing and curing of LFC to ensure compliance with BS-3148.[66] Water was devoid of acids, oils, salts, organic debris, and alkalis. A surfactant derived from proteins was created. An approximate 1:35 ratio of surfactant to water was utilized in the mixture. A Portafoam PM-2 was employed to produce the stable foam, as shown in Figure 1.

Sugarcane bagasse was gathered and processed from a neighboring farm in Penang. The fibrous waste of crushing sugarcane to get its juice is called bagasse. Figure 2 exhibits the physical appearance of SBF before and after the

Figure 1. Production of stable foam using Portafoam PM-2 machine.

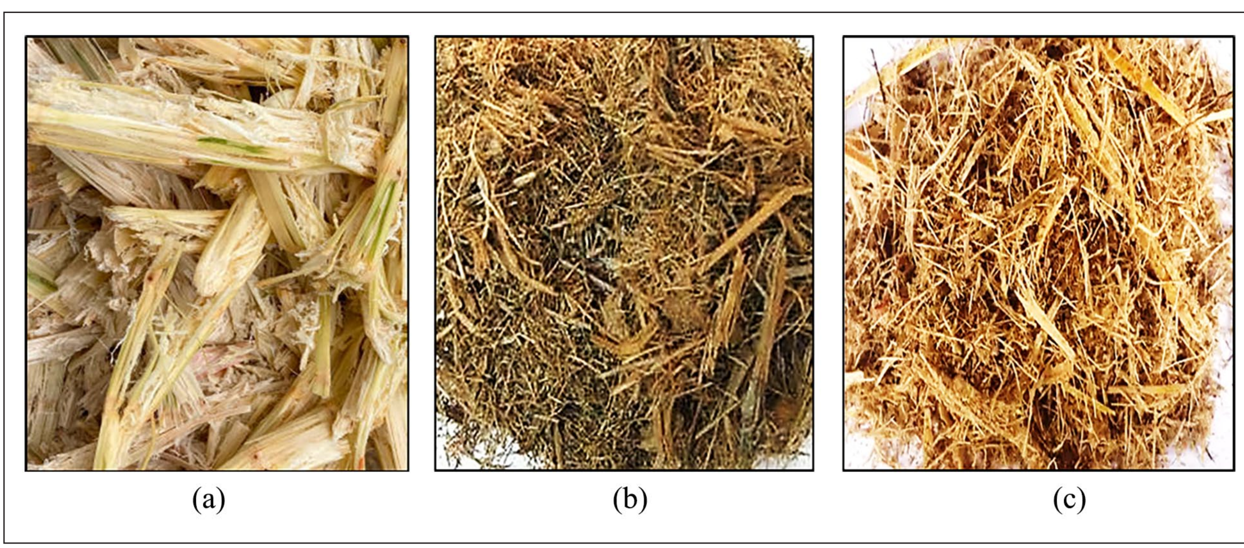

Figure 2. Physical appearance of SBF before and after NaOH treatment: (a) sugarcane bagasse waste, (b) dried untreated SBF, (c) treated SBF (4% NaOH).

NaOH treatment. Figure 2(a) displays bagasse derived from sugarcane. The length of sugarcane bagasse was cut to between 80 and 90 mm. The chopped sugarcane pieces were then pulverized in a machine that was fed with water. Using a drainage device, the products of the ground stem were subsequently washed and dried. The drained, mechanically processed SBF was then air-dried for 48 hours. As demonstrated in Figure 2(b), dried fiber is referred to as untreated SBF (raw fiber). The raw SBF then was subjected to the alkali treatment to enhance its properties. A NaOH concentration of 4% was used to treat SBF. For the 4% NaOH concentration in 10 l of tap water, 400 g of the NaOH pellets were dispersed. The mixture was thoroughly stirred with a long stick for about 4 minutes before introducing the raw SBF into it. A sufficient amount of SBF was then completely submerged in a solution with a concentration of 4% NaOH for the duration of the treatment, which lasted for 24 hours. Table 1 outlines the

Table 1. Mechanical and physical properties of SBF.

Component	Untreated SBF	Treated SBF (4% NaOH)
Tensile strength (N/mm^2)	139	158
Young's modulus (N/mm^2)	14,695	16,500
Elongation at break (%)	5.2	7.8
Length (mm)	19	19
Diameter (um)	24.5	23.7
Density (g/cm^3)	1.25	1.21

Table 2. Chemical composition of SBF.

Constituents	Untreated SBF	Treated SBF (4% NaOH)
Lignin (%)	18.1	15.7
Cellulose (%)	46.8	59.4
Hemicellulose (%)	29.8	23.6
Ash (%)	3.2	0.4
Pectin (%)	0.6	0.1
Extractives (%)	1.5	0.8

Table 3. Mix design of LFC.

Specimen	Density (kg/m^3)	SBF (%)	SBF (kg/m^3)	Binder (kg/m^3)	Filler (kg/m^3)	Water (kg/m^3)	Foam (kg/m^3)
CTRL	800	–	–	302.5	453.7	136.1	36.9
UTF1	800	1	9.29	302.5	453.7	136.1	36.9
TF1	800	1	9.29	302.5	453.7	136.1	36.9
TF2	800	2	18.58	302.5	453.7	136.1	36.9
TF3	800	3	27.87	302.5	453.7	136.1	36.9
TF4	800	4	37.17	302.5	453.7	136.1	36.9
TF5	800	5	46.46	302.5	453.7	136.1	36.9

mechanical and physical characteristics of SBF, whereas Table 2 presents its chemical components. It can be noticed from Table 2 that the mechanical properties of treated SBF were developed in comparison to the untreated SBF.

Mix proportioning

Tests were conducted on seven different LFC mixtures, including a control, UTF1, TF1, TF2, TF3, TF4, and TF5. UTF1 is for the LFC mix design with 1% untreated SBF, whereas TF1–TF5 stand for the LFC mix design with 1%–5% treated SBF. It was also necessary to produce a control LFC so that the results could be assessed. A binder-filler proportion of 1:1.5 was utilized uniformly across all the mixes. A water-binder proportion of 0.45 was applied. The weight fractions of SBF used in FC were 0% (control), 1%, 2%, 3%, 4%, and 5%. The density of LFC was kept within the limit of $800 \pm 25\,kg/m^3$ by maintaining the fresh density at about $930 \pm 25\,kg/m^3$. Table 3 provides the mix design of LFC.

Testing methods

The goals of the experiments were to obtain the thermal conductivity, splitting tensile strength, flexural strength, and compressive strength of LFC reinforced with changing weight fractions of SBF. The compressive strength tests were performed in line with the BS12390-3 specifications.[67] Cube specimens with the dimensions of $100\,mm \times 100\,mm \times 100\,mm$ were employed. Next, the flexural strength tests were done on $100\,mm \times 100\,mm \times 500\,mm$ prisms in accordance with the BS12390-5 requirements.[68] The splitting tensile strength tests were conducted in agreement with the BS12390-6 standard on cylindrical specimens of 100 mm in diameter and 200 mm in height.[69] For these strength properties tests, three LFC specimens were investigated for each curing period. On the other hand, the LFC thermal conductivity with different SBF weight fractions was determined utilizing guarded hot plate apparatus corresponding to ASTM C177.[70] LFC specimens of $10\,mm \times 30\,mm \times 30\,mm$ were prepared. Additionally, a vacuum saturation instrument was used to quantify the permeable porosity of LFC-SBF specimens.[71] Furthermore, scanning electron microscopy (SEM) was employed for analyzing their morphologies.

Results and discussion

Slump flow

The slump flow findings of LFC with the inclusion of several weight fractions are shown in Figure 3. All the mixtures had slump flow diameters that varied from 215 mm to 240 mm. The control LFC (CTRL) with no fiber addition had the greatest slump flow values. The control mix measured a slump flow of 240 mm. As the weight fraction of SBF grew from 1% to 5%, the slump flow was steadily reduced as the fiber became connected to the LFC base mix. Using a 5% weight fraction of SBF, the LFC mixture with the lowest slump flow was achieved. The logged value was 215 mm. By widening the interweaving and resistance between SBF and filler, the inclusion of fiber reduces the flowability and increases the flow resistance, which lead to a considerable reduction in the slump flow diameter. It was found that the slump flow was reduced with increasing the weight fraction of SBF. This is most likely because new

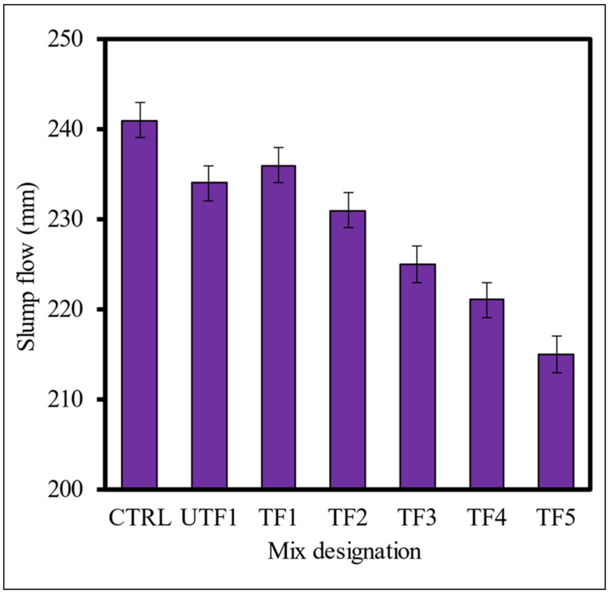

Figure 3. Slump flow of LFC-SBF composites.

LFC combinations have a greater proportion of SBF, which also has higher internal resistance.[51] The slump flow or workability of LFC is a vital fresh-state property to be taken into account during construction, as it can have a significant effect on the durability, strength, labor costs, and visual appeal of the final result. The workability of LFC is crucial for facilitating the ease of pouring it.[72] Construction work becomes very challenging when LFC lacks the workability. Inadequate workable LFC results in insufficient compaction, challenges in managing LFC on-site, and development of honeycombs. An exceptionally workable LFC is characterized by its ability to be easily mixed, carried, put, and compacted during construction processes. This type of concrete is employed in situations when it is impractical to efficiently compress concrete, as well as in the construction of large-scale structures. These varieties of concrete are easily manageable and need minimal effort to harden. Nevertheless, there is a notable possibility of experiencing both a decrease in the homogeneity and occurrence of separation in this particular situation.[73]

Dry density

Figure 4 depicts the effect of different weight fractions of SBF on the density of LFC. In general, Figure 4 exhibits a minor tendency of higher density with the increased weight fractions of SBF, most likely owing to the comparatively high specific gravity of SBF; nevertheless, the difference was not significant. The control LFC mixture recorded the lowest density value of 803, 807, and 811 kg/m^3 on days 7, 28, and 56, respectively. However, the lowest reported density was achieved by adding a 5% weight fraction of

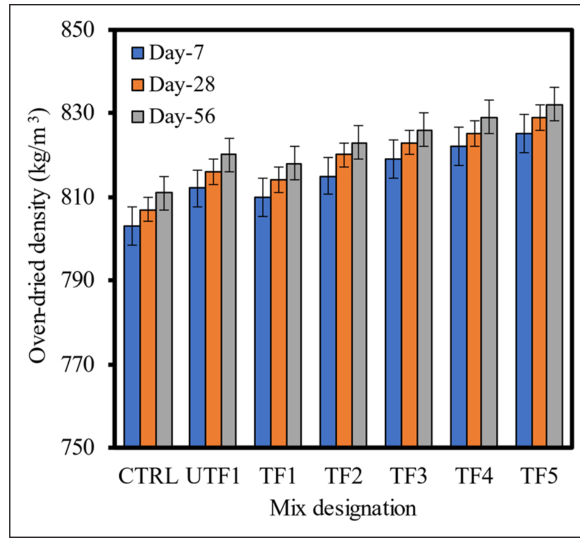

Figure 4. Density of LFC-SBF composites.

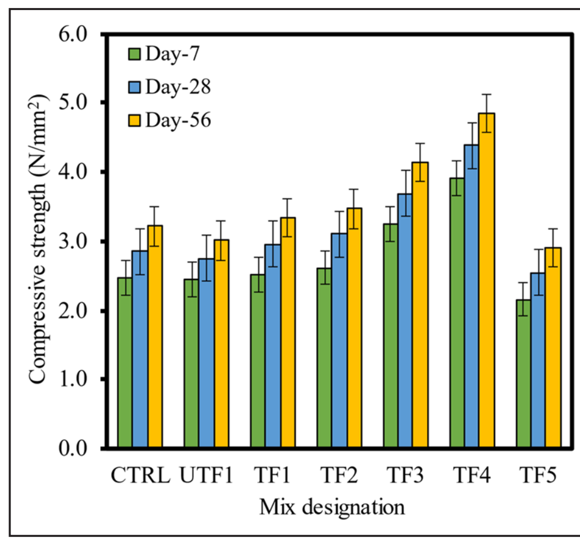

Figure 5. Compressive strength of LFC-SBF composites.

SBF. On days 7, 28, and 56, the recorded densities were 825, 829, and 832 kg/m^3, respectively. Overall, the densities obtained for the entire LFC-SBF combinations are within the allowed range of 50 kg/m^3. On day 28, the dry density deviations from the target density were 7, 16, 14, 20, 23, 25, and 29 kg/m^3 for CTRL, UTF1, TF1, TF2, TF3, TF4, and TF5, respectively.

Compressive strength

Figure 5 displays the findings of the compressive strength with varied weight fractions of SBF. The addition of SBF boosted the LFC's compressive strength. The control LFC specimen had a compressive strength of 2.86 N/mm^2 by

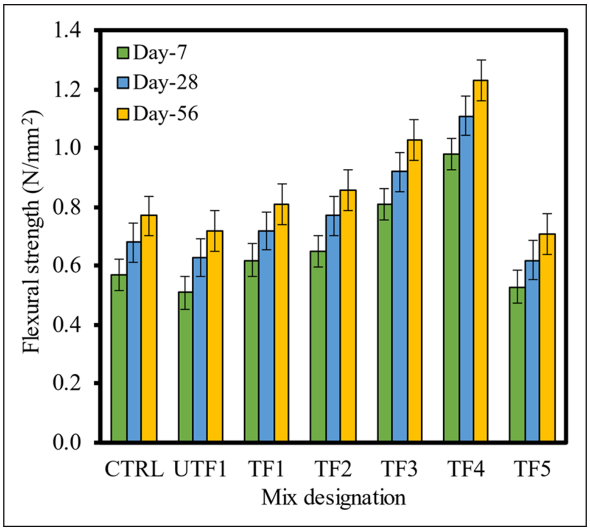

Figure 6. Flexural strength of LFC-SBF composites.

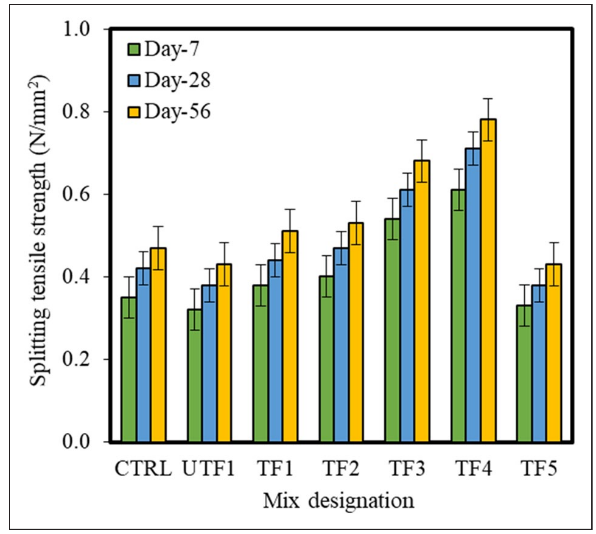

Figure 7. Splitting tensile strength of LFC-SBF composites.

day 28. The maximum compressive strength was obtained with 4% SBF added to LFC. The determined compressive strength was 4.38 N/mm^2 on day 28. When compared to the control specimen, there was an approximately 53% increase in the compressive strength. The compressive strength drastically decreased to 2.55 N/mm^2 on day 28 at a 5% weight fraction of SBF in LFC, which was lower than the control specimen. LFC-SBF composites could support loads with increasing stresses after they had reached their peak compressive strength. SBF absorbs the tensile energy at the interface between SBF and LFC composite and distributes it to the surrounding matrix, lowering the localized tensile stress and enhancing the fracture resistance.[74,75]

Flexural strength

Figure 6 indicates the flexural strength results for the LFC-SBF composites at different weight fractions of SBF. Comparing the control LFC and LFC-SBF specimens to different weight fractions, the flexural strength was generally greater in the LFC-SBF composite mixture with the inclusion of 4% SBF. The flexural strength of 1.11 N/mm^2 was recorded on day 28 using 4% SBF. The observed result was 63% higher than that of the control specimen, which had a flexural strength of 0.68 N/mm^2. The result demonstrated that the flexural strength of LFC was considerably reduced at a 5% weight fraction of SBF. Between SBF and foam cement slurry, an interfacial transition zone often forms.[76] The excessive addition of SBF, particularly to the mix TF5, may result in the increased porosity of LFC, ultimately causing a decrease in the flexural strength. As the cracks spread, SBF is gradually evicted until its bonding capacity is completely exceeded within the LFC cementitious matrix.[77]

Splitting tensile strength

Findings from a splitting tensile strength test performed on the LFC-SBF composite mixes with varying SBF weight fractions are illustrated in Figure 7. The outcomes of the splitting tensile test provide compelling evidence that SBF enhances the overall tensile strength of the LFC mixtures. The control LFC only had a splitting tensile strength of 0.42 N/mm^2 on day 28. The addition of 4% SBF to the LFC mixture increased the splitting tensile strength by a significant amount. On day 28, the splitting tensile strength was 0.71 N/mm^2. The splitting tensile strength at the point of fracture was increased by almost 69% compared to the control LFC specimen. The addition of SBF to the LFC mixtures ensures that LFC will continue to function as a fastener even if it develops microcracks. All strains at the onset of cracking will be absorbed by SBF, and then gradually transferred to the binder matrix. Nevertheless, when SBF was included at a weight fraction of 5%, the LFC's splitting tensile strength dropped dramatically. This might be due to uneven distribution of SBF in the LFC cementitious matrix.[78]

Relationship between strength properties

A method that establishes a connection between a dependent variable and one or more independent variables is known as a regression analysis. It is feasible to show if the variations in the dependent variable are related to variations in one or more of the explanatory variables. Figures 8 to 10 display the relationships that exist between the compressive and flexural strengths, splitting tensile and compressive strengths, and flexural and splitting tensile strengths, respectively. The data arrangement in these three figures supports the hypothesis of a remarkable

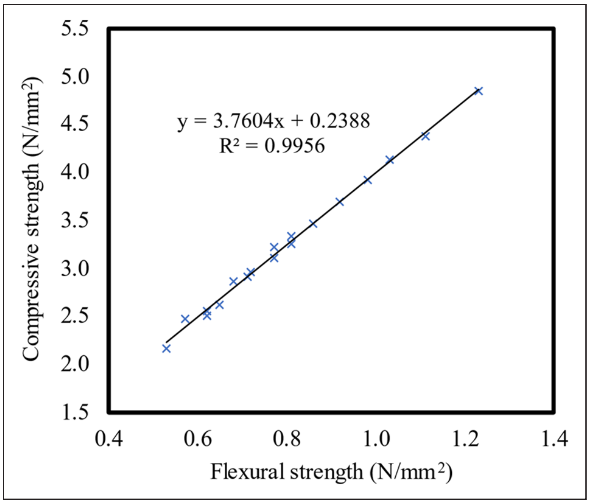

Figure 8. Compressive-flexural strengths of LFC-SBF composites.

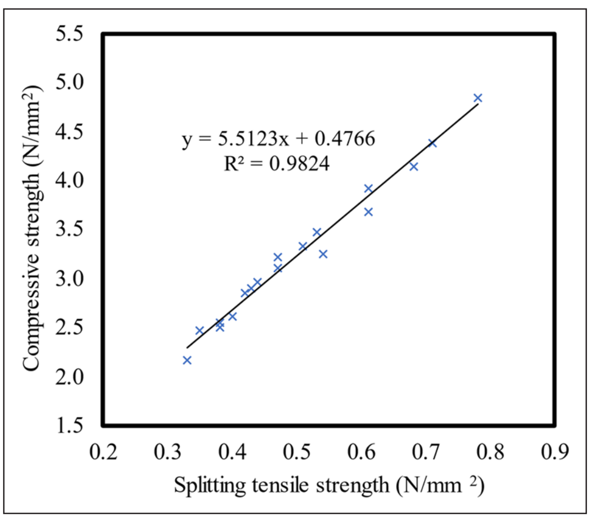

Figure 9. Compressive-splitting tensile strengths of LFC-SBF composites.

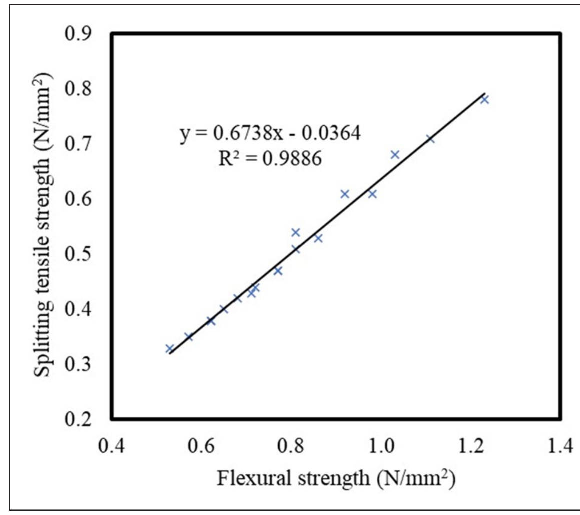

Figure 10. Splitting tensile-flexural strengths of LFC-SBF composites.

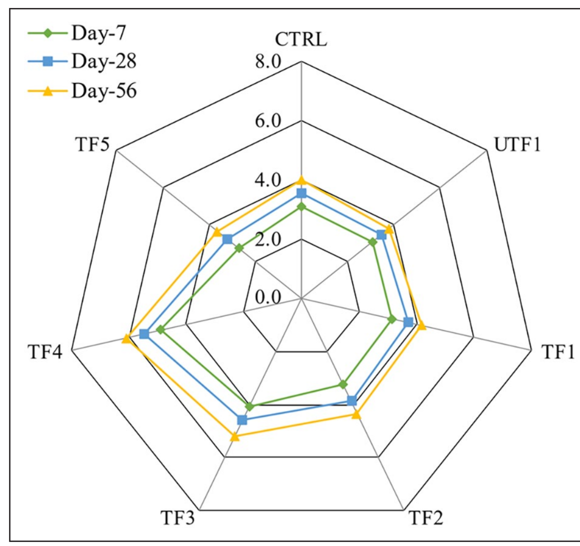

Figure 11. Performance index of LFC-SBF composites.

correlation between the strong features of LFC enhanced by SBF. There is a significant linear relationship with the R^2 values of 0.99 for the compressive-flexural strengths, 0.98 for compressive-splitting tensile strengths, and 0.99 for splitting tensile-flexural strengths.

Performance index

There exists a correlation between the compressive strength and density of LFC. Theoretically, the LFC's compressive strength increases with its density. To conduct this study, we maintained a density of 800 kg/m^3 of LFC. Since the addition of SBF caused modest variations in the density between specimens, the performance index of the LFC-SBF composites was determined to improve the reliability of the experimental findings. The efficiency index of the 800 kg/m^3 specimen used in this analysis is exhibited in Figure 11. The performance index found a similar pattern, with the index rising in a direct correlation to the specimen's curing age. The LFC-SBF composites with 4% SBF (mixture TF4) had a performance index of 5.18 N/mm^2 per 1000 kg/m^3, making them the most effective after 56 days. The compressive and toughness properties of LFC are both improved by the addition of SBF. In addition, the use of SBF in the cementitious matrix improves the LFC's cracking resistance and expansion ability. This is because the SBF bridging effect stops the transverse deformation of concrete, which leads to an increase in the compressive strength of LFC. The addition of SBF at lower weight fractions (between 1% and 4%)

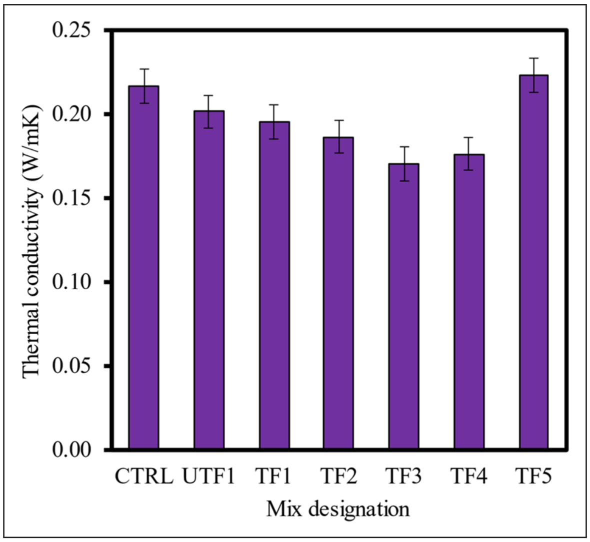

Figure 12. Thermal conductivity of LFC-SBF composites.

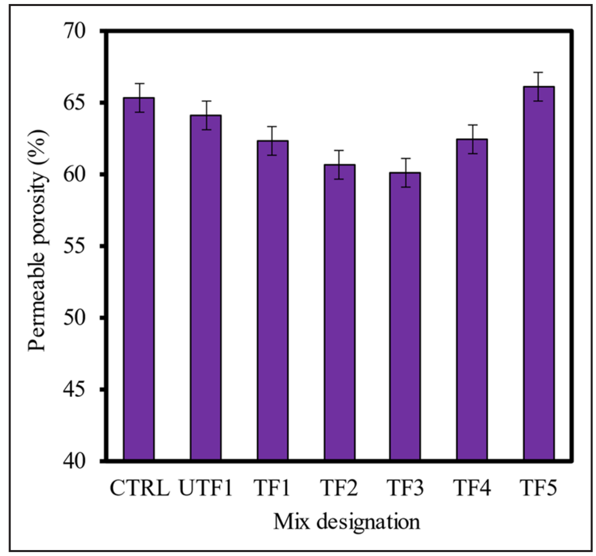

Figure 13. Permeable porosity of LFC-SBF composites.

strengthens the link between the components of the composite and enables the establishment of a bound that is uninterrupted. Moreover, increasing the pace at which SBFs are introduced into LFC results in an increase in voids, which may lead to a drop in the compressive strength of LFC (at 5% weight fraction).

Thermal conductivity

Figure 12 depicts the thermal conductivity values of LFC with different weight fractions of SBF. As indicated in the figure, adding SBF to LFC may aid in lowering the material's thermal conductivity. The ideal thermal conductivity value was obtained with a SBF weight fraction of 3%. The recorded thermal conductivity value for the control specimen was 0.2167 W/mK. The thermal conductivity of LFC was considerably reduced to 0.1704 W/mK with the addition of 3% SBF by weight. When the weight fraction of SBF rises, the thermal conductivity of the material increases because LFC with SBF has a porous structure that allows it to absorb heat. The addition of SBF also contributes to reallocation and the development of smaller, more regular void sizes, both of which help explain the LFC's very low thermal conductivity. The investigations also demonstrated that SBF has a noticeable amount of untapped potential for use in cement-based materials, where it may be vital in lowering the thermal-inducing characteristic of produced concrete or improving its heat transmission. The use of SBF also facilitates the redistribution and formation of smaller, more uniform empty spaces, which in turn elucidates the remarkably low thermal conductivity of LFC. The studies also revealed that SBF possesses a substantial amount of unexplored capacity for utilization in cement-based materials. This capacity could be crucial in reducing the thermal-inducing properties of manufactured concrete or enhancing its heat conduction.[79]

Permeable porosity

Figure 13 illustrates the influence of different weight fractions of SBF on the permeable porosity of LFC. A rise in the weight fraction of SBF results in a reduction in its permeable porosity. It was found that the permeable porosity of LFC was at its lowest value as 60.1%, when a 3% weight fraction of SBP was used. In contrast, the largest permeable porosity in the control FC was 65.0%. The permeable porosity showed an increase of around 7.5% when treated with a 3% SBF, compared to the control specimen. The SBF changes in morphology lead to a reduction in the permeable porosity of LFC. Increasing the weight fraction of SBF to its optimal level in LFC enhances the cohesion of the matrix, resulting in a reduction in the porosity of LFC. The decrease in the permeability porosity percentage can be ascribed to the reduced water absorption of LFC or the effects of void packing generated by the presence of SBF.[80] The compatibility of SBF with a cementitious matrix has a notable influence on the moisture absorption and porosity behavior, depending on the characteristics of SBF. Because of their remarkable ability to withstand the permeable porosity, LFC-SBF hybrids exhibit a high level of resilience to the porosity.

Morphology evaluation

Figures 14 and 15 display the SEM results of untreated and treated SBF, respectively. The morphology of SBF after treatment (Figure 14) varied significantly from that of the untreated one (Figure 15). For the untreated SBF, the existence of impurities and debris on the fiber surface will lead

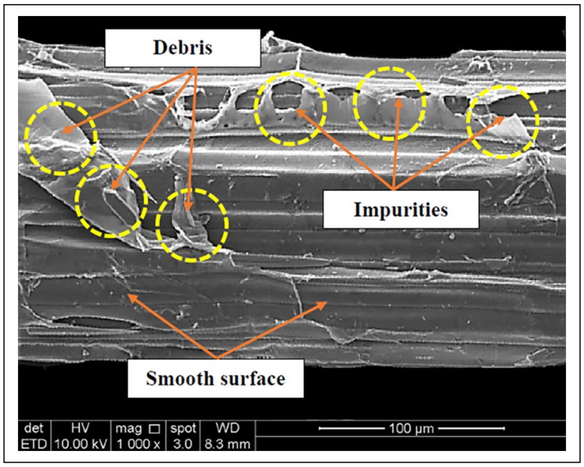

Figure 14. Morphology of untreated SBF.

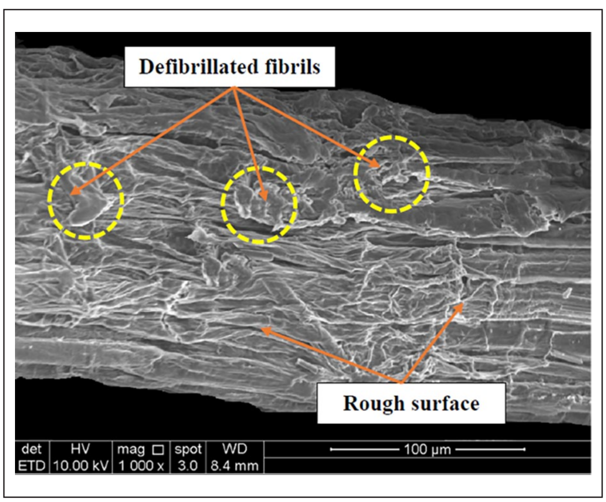

Figure 15. Morphology of treated SBF.

to a frail interfacial bond between the fiber and the LFC cementitious composites. Moreover, the presence of plain and smooth surfaces with only visible scaly lines is not good for an interfacial bond. Following the 4% NaOH treatment, the morphological structure of SBF underwent a clear change. The fiber demonstrated significant enhancements in terms of purity, roughness, and absence of surface impurities.[81] Besides, the fiber surface looks very rough and deformed. The interaction of sodium with the surface during the treatment removed the wax and cuticle, suffocating the fiber surface. It is visible on the surface of loose isolated fibrils which are defibrillated due to the action of the NaOH treatment. The removal of the binding substances and the development of some micropores in the treated SBF were found to be the causes of the defibrillated process. It was also indicated that exposing more fibrils by removing the superficial layer might enhance the surface area in contact with the LFC cementitious composites. The surface area for an efficient interfacial connection

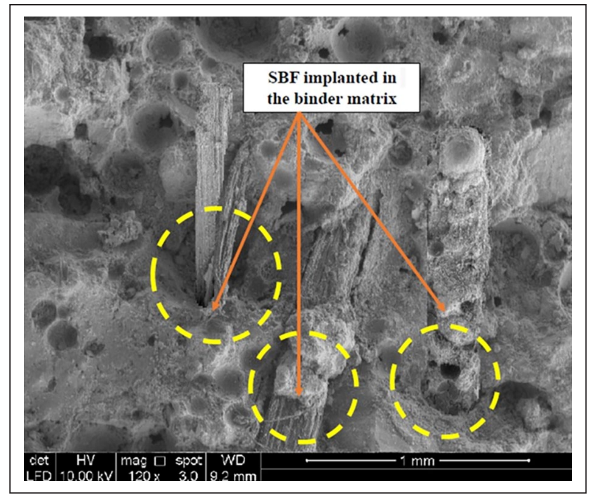

Figure 16. SEM results of LFC-SBF composites with a 4% weight fraction of fiber.

between the SBF surface and binder matrix is increased by these loose fibrils on the rough surface, as illustrated in Figure 16. The elimination of surface contaminants on fibers helps the LFC-SBF adhesion because it makes mechanical interweaving and the bonding reaction easier.

Conclusions

The strength properties and thermal conductivity of LFC-SBF composites were investigated by adding different weight fractions of SBF. When the weight fraction of SBF increased from 1% to 5%, the slump flow decreased progressively. The lowest slump flow was achieved by inserting a 5% weight fraction of SBF into the LFC mixture. The density of the LFC-SBF composites increased due to the SBF's comparatively high specific gravity and rising weight fraction, nonetheless, the difference was not substantial. The inclusion of SBF in the LFC mixture contributed significantly to its splitting tensile, flexural, and compressive strengths. The ideal strength properties were obtained by adding a 4% SBF to LFC. When SBF was added to the LFC mixes, it assured that LFC would work as a fastener when microcracks formed. Also, when SBF was present, the thermal conductivity of LFC was improved noticeably. Owing to the porous structure of LFC with SBF, which enabled it to absorb heat, as the weight fraction of SBF in LFC increased, so did the material's thermal conductivity. The low thermal conductivity of LFC achieved was mostly owing to the redistribution and creation of a smaller regular pore size, which was aided by the incorporation of SBF. The best results were obtained by including a 3% weight fraction of SBF in LFC. This research work has provided important data for future investigation of SBF-reinforced LFC.

Data availability statement

The datasets used and/or analyzed during the current study are made available from the corresponding authors on reasonable request.

Declaration of conflicting interests

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References

1. Manzano-Agugliaro F, Montoya FG, Sabio-Ortega A, et al. Review of bioclimatic architecture strategies for achieving thermal comfort. *Renew Sustain Energ Rev* 2015; 49: 736–755.
2. Zhang Y, Wang J, Hu F, et al. Comparison of evaluation standards for green building in China, Britain, United States. *Renew Sustain Energ Rev* 2017; 68: 262–271.
3. Bressand F, Farrell D, Haas P, et al. *Curbing global energy demand growth: the energy productivity opportunity. McKinsey Glob Inst*. Sao Paulo, Brazil: McKinsey & Company, 2007. pp.1–290.
4. Mounir S, Khabbazi A, Khaldoun A, et al. Thermal inertia and thermal properties of the composite material clay–wool. *Sustain Cities Soc* 2015; 19: 191–199.
5. Loh YR, Sujan D, Rahman ME, et al. Sugarcane bagasse—The future composite material: a literature review. *Resour Conserv Recycl* 2013; 75: 14–22.
6. Manohar K. Experimental investigation of building thermal insulation from agricultural by-products. *Br J Appl Sci Technol* 2012; 2(3): 227–239.
7. Aminudin E, Khalid NHA, Azman NA, et al. Utilization of baggase waste based materials as improvement for thermal insulation of cement brick. In: *International Symposium on Civil and Environmental Engineering 2016 (ISCEE 2016), Melaka, Malaysia*, 2017, p.103.
8. Canilha L, Chandel AK, Suzane dos Santos Milessi T, et al. Bioconversion of sugarcane biomass into ethanol: an overview about composition, pretreatment methods, detoxification of hydrolysates, enzymatic saccharification, and ethanol fermentation. *J Biomed Biotechnol* 2012; 2012: 1–15.
9. Saradar A, Tahmouresi B, Mohseni E, et al. Restrained shrinkage cracking of fiber-reinforced high-strength concrete. *Fibers* 2018; 6(1): 12.
10. Iqbal S, Ali A, Holschemacher K, et al. Mechanical properties of steel fiber reinforced high strength lightweight self-compacting concrete (SHLSCC). *Constr Build Mater* 2015; 98: 325–333.
11. Husem M. The effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete. *Fire Saf J* 2006; 41(2): 155–163.
12. Maglad AM, Othuman Mydin MA, Dip Datta S, et al. Assessing the mechanical, durability, thermal and microstructural properties of sea shell ash based lightweight foamed concrete. *Constr Build Mater* 2023; 402: 133.
13. Maglad AM, Othuman Mydin MA, Majeed SS, et al. Development of eco-friendly foamed concrete with waste glass sheet powder for mechanical, thermal, and durability properties enhancement. *J Build Eng* 2023; 80: 107974.
14. Nawi M, Lee A, Osman W, et al. Supply chain management (SCM): disintegration team factors in Malaysian Industrialised Building System (IBS) construction projects. Int J *Supply Chain Manag* 2018; 7(1): 140–143.
15. Mydin MAO, Phius AF, Sani NM, et al. Potential of green construction in Malaysia: industrialised building system (IBS) vs traditional construction method. In: *Emerging Technology for Sustainable Development Congress (ETSDC 2014), Penang, Malaysia*, 2014, p.3.
16. Tambichik MA, Abdul Samad AA, Mohamad N, et al. Effect of combining palm oil fuel ash (POFA) and rice husk ash (RHA) as partial cement replacement to the compressive strength of concrete. *Int J Integr Eng* 2018; 10(8): 61–67.
17. Amran YHM. Influence of structural parameters on the properties of fibred-foamed concrete. *Innov Infrastruct Solut* 2020; 5(1): 16.
18. Lesovik V, Voronov V, Glagolev E, et al. Improving the behaviors of foam concrete through the use of composite binder. *J Build Eng* 2020; 31: 17.
19. Musa M, Mydin MAO and Ghani ANA. Influence of oil palm empty fruit bunch (EFB) fibre on drying shrinkage in restrained lightweight foamed mortar. *Int J Innov Technol Exp Eng* 2019; 8(10): 4533–4538.
20. Mohamad N, Samad AAA, Lakhiar MT, et al. Effects of incorporating banana skin powder (BSP) and palm oil fuel ash (POFA) on mechanical properties of lightweight foamed concrete. *Int J Int Eng* 2018; 10(9): 169–176.
21. Amran YHM, Farzadnia N and Abang Ali AA. Properties and applications of foamed concrete; a review. *Constr Build Mater* 2015; 101: 990–1005.
22. Mohamad N, Iman MA, Othuman Mydin MA, et al. Mechanical properties and flexure behaviour of lightweight foamed concrete incorporating coir fibre. *IOP Conf Ser Earth Sci* 2018; 140: 012140.
23. Raj A, Sathyan D and Mini KM. Physical and functional characteristics of foam concrete: a review. *Constr Build Mater* 2019; 221: 787–799.
24. Mydin MAO, Nawi MNM, Omar R, et al. The use of inorganic ferrous-ferric oxide nanoparticles to improve fresh and durability properties of foamed concrete. *Chemosphere* 2023; 317: 137661.

25. Nambiar EKK and Ramamurthy K. Influence of filler type on the properties of foam concrete. *Cem Concr Compos* 2006; 28(5): 475–480.
26. Nensok MH, Mydin MAO and Awang H. Investigation of thermal, mechanical and transport properties of ultra-lightweight foamed concrete (ULFC) strengthened with alkali treated banana fibre. *J Adv Res Fluid Mech Therm Sci* 2021; 86(1): 123–139.
27. Ganesan S, Othuman Mydin MA, Sani NM, et al. Performance of polymer modified mortar with different dosage of polymeric modifier. In: *Building Surveying, Facilities Management and Engineering Conference (BSFMEC 2014), Penang, Malaysia,* 2014, p.15.
28. Mydin MAO, Zamzani NM and Ghani ANA. Effect of alkali-activated sodium hydroxide treatment of coconut fiber on mechanical properties of lightweight foamed concrete. In: *3rd International Conference on Applied Science and Technology (ICAST'18), Penang, Malaysia*, 2018, 2016, p.020108. DOI: 10.1063/1.5055510
29. Narayanan N and Ramamurthy K. Structure and properties of aerated concrete: a review. *Cem Concr Compos* 2000; 22(5): 321–329.
30. Mindess S. *Developments in the formulation and reinforcement of concrete*. Sawston, UK: Woodhead Publishing, 2019.
31. Mydin MAO. Mechanical properties of foamed concrete reinforced with natural fibre. *J Eng Sci Technol* 2022; 17(6): 4144–4162.
32. Serri E, Othuman Mydin MA and Suleiman MZ. The influence of mix design on mechanical properties of oil palm shell lightweight concrete. *J Mater Env Sci* 2015; 6(3): 607–612.
33. Serri E, Suleiman MZ and Mydin MAO. The effects of oil palm shell aggregate shape on the thermal properties and density of concrete. *Adv Mat*er *Res* 2014; 935: 172–175.
34. Nensok MH, Mydin MAO and Awang H. Fresh state and mechanical properties of ultra-lightweight foamed concrete incorporating alkali treated banana fibre. *J Teknol* 2021; 84(1): 117–128.
35. Othuman Mydin MA, Mohamed Shajahan MF, Ganesan S, et al. Laboratory investigation on compressive strength and micro-structural features of foamed concrete with addition of wood ash and silica fume as a cement replacement. *MATEC Web Conf* 2014; 17: 01004.
36. Othuman Mydin M A. and Mohd Zamzani N. Coconut fiber strengthen high performance concrete: Young's modulus, ultrasonic pulse velocity and ductility properties. *Int J Eng Technol* 2018; 7(2.23): 284–287.
37. Bayraktar OY, Yarar G, Benli A, et al. Basalt fiber reinforced foam concrete with marble waste and calcium aluminate cement. *Struct Concr* 2023; 24(1): 1152–1178.
38. Bayraktar OY, Soylemez H, Kaplan G, et al. Effect of cement dosage and waste tire rubber on the mechanical, transport and abrasion characteristics of foam concretes subjected to H2SO4 and freeze–thaw. *Constr Build Mater* 2021; 302: 124229.
39. Gencel O, Yavuz Bayraktar O, Kaplan G, et al. Lightweight foam concrete containing expanded perlite and glass sand: Physico-mechanical, durability, and insulation properties. *Constr Build Mater* 2022; 320: 126187.
40. Othuman Mydin MA, Rozlan NA, Sani NM, et al. Analysis of micro-morphology, thermal conductivity, thermal diffusivity and specific heat capacity of coconut fibre reinforced foamed concrete. *MATEC Web Conf* 2014; 17: 01020.
41. Siddique R and Cachim P. *Waste and Supplementary Cementitious Materials in Concrete: Characterisation, Properties and Applications*. Sawston, United Kingdom: Woodhead Publishing, 2018, pp.1–599.
42. Othuman M M.A, Rozlan NA and Ganesan S. Experimental study on the mechanical properties of coconut fibre reinforced lightweight foamed concrete. *J Mater Env Sci* 2015; 6(3): 407–411.
43. Sayadi AA, Tapia JV, Neitzert TR, et al. Effects of expanded polystyrene (EPS) particles on fire resistance, thermal conductivity and compressive strength of foamed concrete. *Constr Build Mater* 2016; 112: 716–724.
44. Othuman M M.A and Soleimanzadeh S. Effect of polypropylene fiber content on flexural strength of lightweight foamed concrete at ambient and elevated temperatures. *Adv Appl Sci Res* 2012; 3(1): 2837–2846.
45. Abbas W, Dawood E and Mohammad Y. Properties of foamed concrete reinforced with hybrid fibres. In: *MATEC Web of Conferences*. Les Ulis, France, EDP Sciences, 2018; p.162.
46. Amarnath Y and Ramachandrudu C. Properties of foamed concrete with sisal fibre. In: *Proceedings of the 9th international concrete conference 2016: environment, efficiency and economic challenges for concrete*, Dundee, UK, University of Dundee, 4–6 July 2016.
47. Dawood ET and Hamad AJ. Toughness behaviour of high-performance lightweight foamed concrete reinforced with hybrid fibres. *Struct Concr* 2015; 16(4): 496–507.
48. Falliano D, De Domenico D, Ricciardi G, et al. Compressive and flexural strength of fiber-reinforced foamed concrete: effect of fiber content, curing conditions and dry density. *Constr Build Mater* 2019; 198: 479–493.
49. Fedorov V and Mestnikov A. Influence of cellulose fibers on structure and properties of fiber reinforced foam concrete. In: *MATEC web of conferences*; Les Ulis, EDP Sciences, 2018; Vol. 143, p.02008.
50. Liu Y, Wang Z, Fan Z, et al. Study on properties of sisal fiber modified foamed concrete. *IOP Conf Ser Mater Sci Eng* 2020; 744(1): 012042.
51. Yavuz Bayraktar O, Kaplan G, Gencel O, et al. Physico-mechanical, durability and thermal properties of basalt fiber reinforced foamed concrete containing waste marble powder and slag. *Constr Build Mater* 2021; 288: 123128.
52. Gencel O, Nodehi M, Yavuz Bayraktar O, et al. Basalt fiber-reinforced foam concrete containing silica fume: an experimental study. *Constr Build Mater* 2022; 326: 126861.
53. Mahzabin MS, Hock LJ, Hossain MS, et al. The influence of addition of treated kenaf fibre in the production and properties of fibre reinforced foamed composite. *Constr Build Mater* 2018; 178: 518–528.
54. Gómez Hoyos C and Vázquez A. Flexural properties loss of unidirectional epoxy/fique composites immersed in water and alkaline medium for construction application. *Compos Part B Eng* 2012; 43(8): 3120–3130.

55. Faruk O, Bledzki AK, Fink HP, et al. Biocomposites reinforced with natural fibers: 2000–2010. *Polym Sci* 2012; 37(11): 1552–1596.
56. Liu Y, Ma Y, Yu J, et al. Development and characterization of alkali treated abaca fiber reinforced friction composites. *Compos Interfaces* 2019; 26(1): 67–82.
57. Godara SS. Effect of chemical modification of fiber surface on natural fiber composites: a review. *Mater Today Proc* 2019; 18: 3428–3434.
58. Yan L, Chouw N and Yuan X. Improving the mechanical properties of natural fibre fabric reinforced epoxy composites by alkali treatment. 2012; 31(6): 425–437.
59. Siddika S, Mansura F, Hasan M, et al. Effect of reinforcement and chemical treatment of fiber on the properties of jute-coir fiber reinforced hybrid polypropylene composites. *Fibers Polym* 2014; 15(5): 1023–1028.
60. Sedan D, Pagnoux C, Smith A, et al. Mechanical properties of hemp fibre reinforced cement: influence of the fibre/matrix interaction. *J Eur Ceram Soc* 2008; 28(1): 183–192.
61. Li Y, Chai J, Wang R, et al. Utilization of sugarcane bagasse ash (SCBA) in construction technology: a state-of-the-art review. *J Build Eng* 2022; 56: 104774.
62. Rathi KLP and Vaishali VR, DG Effect of sugarcane bagasse ash on strength properties of concrete. *Int J Res Eng Technol* 2016; 05(04): 159–164.
63. Danso H, Brett Martinson D, Ali M, et al. Effect of sugarcane bagasse fibre on the strength properties of soil blocks. In: *1st international conference on bio-based building materials*, Clermont-Ferrand, France, 2015, pp.1–7.
64. Mangi SA, Jamaluddin N, Wan Ibrahim MH, et al. Utilization of sugarcane bagasse ash in concrete as partial replacement of cement. *IOP Conf Ser Mater Sci Eng* 2017; 271: 012001.
65. BS EN 197-1. *Cement - composition, specifications and conformity criteria for common cements*. London, UK: British Standards Institute, 2011.
66. BS EN 3148. *Water for making concrete (including notes on the suitability of the water*. London, UK: British Standards Institute, 1980.
67. BS12390-3. *Testing hardened concrete. Compressive strength of test specimens*. London, UK: British Standards Institute, 2011.
68. Bs EN 12390-5. *Testing hardened concrete. Flexural strength of test specimens*. London, UK: British Standards Institute, 2019.
69. Bs EN. *Testing hardened concrete. Tensile splitting strength of test specimens*. London, UK: British Standards Institute, 2009. pp.12390–12396.
70. ASTM C177. *Thermal conductivity test*. West Conshohocken, PA: ASTM International, 2019.
71. Cabrera JG and Lynsdale CJ. A new gas permeameter for measuring the permeability of mortar and concrete. *Mag Concr Res* 1988; 40(144): 177–182.
72. Othuman Mydin MA. Effect of silica fume and wood ash additions on flexural and splitting tensile strength of lightweight foamed concrete. *J Teknol* 2015; 74(1): 125–129.
73. Hassan Nensok M, Othuman Mydin MA and Awang H. Optimization of mechanical properties of cellular lightweight concrete with alkali treated banana fiber. *Rev de Clin Constr* 2021; 20(3): 491–511.
74. Gencel O, Kazmi SMS, Munir MJ, et al. Influence of bottom ash and polypropylene fibers on the physico-mechanical, durability and thermal performance of foam concrete: an experimental investigation. *Constr Build Mater* 2021; 306: 124887. Doi: 10.1016/j.conbuildmat.2021.124887.
75. Awang H, Mydin MAO and Roslan AF. Effects of fibre on drying shrinkage, compressive and flexural strength of lightweight foamed concrete. *Adv Mater Res* 2012; 587: 144–149.
76. Jones MR and Giannakou A. Preliminary views on the application of foamed concrete in structural sections using pulverized fuel ash as cement or fine aggregate. *Mag Concr Res* 2010; 57(1): 21–31.
77. Yu B, Zhou J, Cheng B, et al. Compressive strength development and microstructure of magnesium phosphate cement concrete. *Constr Build Mater* 2021; 283: 122585.
78. Mydin MAO, Mohamad N, Samad AAA, et al. Durability performance of foamed concrete strengthened with chemical treated (NaOH) coconut fiber. In: *3rd International Conference on Applied Science and Technology (ICAST'18), Penang, Malaysia*, 2016, 2018, p.020109. DOI: 10.1063/1.5055511
79. Suhaili SS, Mydin MAO and Awang H. Influence of mesocarp fibre inclusion on thermal properties of foamed concrete. *J Adv Res Fluid Mech Therm Sci* 2021; 87(1): 1–11.
80. Roslan AF, Awang H and Mydin MAO. Effects of various additives on drying shrinkage, compressive and flexural strength of lightweight foamed concrete (LFC). *Adv Mater Res* 2012; 626: 594–604.
81. Le DH, Sheen YN and Lam MNT. Self-compacting concrete with sugarcane bagasse ash – ground blast furnace slag blended cement: fresh properties. *IOP Conf Ser Earth Sci* 2018; 143(1): 012019.