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INFLUENCE OF UNTREATED ABACA FIBRE ON MECHANICAL PROPERTIES OF LIGHTWEIGHT FOAMED CONCRETE

Md Azree OTHUMAN MYDIN *

*Associate Prof.; School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia
E-mail address: *azree@usm.my*

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Abstract

Presently, the expenditure on construction materials grows dramatically along with the enduring effect on the ecosystem, and it has led the academics to the recognition of natural plant fibres such as abaca fibre (AF) for enhancing the mechanical properties of concrete. AF is plentifully obtainable making it fairly relevant to be employed as a strengthening material in lightweight foamed concrete (LFC). Moreover, natural plant fibre-reinforced concrete has been progressively utilized in construction for several decades to decrease crack growth under the static load. This paper anticipates examining the effectiveness of the addition of AF in LFC to enhance its mechanical properties. LFC specimens of 550 kg/m^3 density were reinforced with AF at weight fractions of 0.00%, 0.15%, 0.30%, 0.45% and 0.60%. Three parameters have been assessed which were flexural strength, compressive strength and tensile strength. The results revealed that adding 0.45% AF into LFC enables optimal compressive, flexural and splitting tensile strengths. The presence of AF augments material strength by filling spaces, micro-cracks, and gaps inside the LFC structure. Additionally, AF helped reduce crack spreading when the plastic state of the LFC cementitious matrix was loaded. Though, further, than the optimum level of AF addition, accumulation and the non-uniform distribution of AF were identified, which triggers the lowering of the LFC strength properties substantially. The output of this preliminary investigation would give a better understanding of the potential utilization of plant fibre in LFC. It is of great importance to drive the sustainable development and application of LFC material and infrastructures.

Keywords: **Foamed concrete; Mechanical properties; Compressive strength; Flexural; Tensile.**

1. INTRODUCTION

Nowadays, adopting a green environment in the construction industry has been a severe issue in Malaysia for a few last years. It can be seen clearly in the Malaysian Construction Industry Master Plan (2005–2015) [1]. There are a few initiatives that the government and private sectors in Malaysia undertake to attract the players in the construction industry to adopt with sustainable expansion and green buildings. The green building aims to reduce carbon dioxide released into the atmosphere. To achieve these, all construction industry players in Malaysia need to achieve the Green Building Index (GBI) requirements, which is introduced in 2005 to increase the awareness among the construction players and support sustainable construction in the built environment.

Moreover, the global concern for eco-friendly construction has driven a lot of research on green concrete worldwide. The research that uses materials and processes resource-efficient and environmental throughout the life cycle has been increased [2]. In some cases, special attention has been given to areas such as concrete mix design, mix material sourcing, method of construction and technology, and concrete structure preservation. Thus, it can be concluded that achieving sustainable development in society depends on the significant role played by the industry players.

Generally, most construction materials are produced from non-sustainable products that need a high amount of energy to cause a global problem. Therefore, natural fibre in LFC can be used in concrete production, contributing to solving these problems. There are various advantages when using LFC in construction, such as delivering good thermal insulation, superior fire resistance, lightweight and reducing few materials in concrete like cement, fine aggregates, stable foam, and water. These materials are common in LFC. Another admixture can be added to it to improve the strength of LFC. Furthermore, the absence of coarse aggregates in LFC caused it to reduce weight. As identified, LFC can function for structural and non-structural elements as well as thermal insulating materials. There are various types of density in LFC, ranging from 300–1700 kg/m^3 [3]. On another note, LFC is more eco-friendly, inflammable, and easy to produce compared to other materials. Unfortunately, making LFC takes a longer time than conventional concrete to ensure proper mixing. In the last two decades, LFC has seen global use for many applications: bulk filler, backfill for wall retention, trench reinstatement, building supports, tiles, insulator, soundproofing material, tunnel grouting substance, inner filler for precast projects, pipeline filler, and FC soil specifically to construct embankment slopes. The last few years have drawn attention to FC applications for semi- and non-structural applications in construction works because they are lightweight and have superior insulation characteristics [4].

LFC is comparatively brittle at normal stress or impact loadings. It has a tensile strength of about 10% of the compressive strength. Thus, LFC must be strengthened using continuous reinforcement to better bear stress and offset the effects of low strength and ductility. Furthermore, steel-based reinforcement is employed to improve the tensile and shear stress handling capacity for critical points on the LFC. Steel-based LFC reinforcement significantly improves strength; though, it is crucial to control the microcrack formation to produce LFC with homogenous tensile attributes [5]. According to Johnson et al. [6], the strength of LFC under compression is influenced by its density, types of cement and its content, water to cement ratio, foaming agent type and shape and size of the voids. Compressive strength reduces exponentially with decreasing LFC density. Meanwhile, the access of air bubbles and the interrelation between them will increase seriously because of the reduction of density. For that reason, the water vapour will rise and cause a reduction in LFC strength. Nevertheless, the vulnerability of LFC under tensile load can be overcome by combining a certain number of natural fibres. The fibres can arrest the formation of cracks and enhance the ductility and strength of LFC [7].

Numerous studies have been undertaken on this subject and have established the efficiency of fibres in mixtures in terms of durability and increase in mechanical qualities. Based on studies by Feng et al. [8], there are benefits and shortcomings. It can be grouped into synthetic fibres made by humans and natural fibres produced from plants, animals, and geological processes. An excellent essence is the most delicate fibres that improve LFC's strength, properties, ductility, and shrinkage. Additionally, natural fibres are considered sustainable resources, which is one of the primary reasons why synthetic fibre is gaining so much attention. Natural fibres have several advantages over synthetic fibres, including the fact that they are biodegradable, have a low density, and are difficult to melt when heated. Natural fibres can be used to reinforce cementitious materials, particularly when developing and fabricating building materials. Bamboo, banana, coir, cane, and henequen are all examples of natural fibres [9]. Natural fibres are widely used in lightweight concrete production because they are more environmentally friendly and cost-effective in the building sector than synthetic fibres. Regardless of this, the primary goal of incorporating fibres into cementitious materials is to increase LFC's durability and mechanical qualities. According to Chandni [10], fibres can strengthen the bonding in LFC, hence increasing its tensile strength and structural integrity.

The integration of natural fibres into LFC increases its mechanical properties. It has been confirmed that a low volumetric of the short natural fibres (18–25 mm) decreases the effect of early age on the strength properties of LFC. It is crucial to recognize the number of fibres, sand, cement, water and foaming agent in the mixture. There were some efforts by various researchers to determine the mechanical properties of LFC strengthened with natural fibres. Liu et al. [11] found that combining a 0.75% weight fraction of sisal fibre into LFC enhanced its drying shrinkage and mechanical properties. Nensok Hassan et al. [12] employed natural banana fibre in LFC. They found that banana fibre acted well in the LFC cementitious matrix to enhance the bond between the LFC's cement matrix and the fibre hence expanding the mechanical properties of the composite. Flores-Johnson et al. [13) reported an improvement in the mechanical properties of LFC with densities of 800 kg/m^3 and 900 kg/m^3 with the inclusion of henequen fibres. Amarnath and Ramachandrudu [14] acknowledged that the use of sisal fibre as a strengthening material in 1200 kg/m^3 density improved the compressive and tensile strengths. Raj et al. [15] assessed the engineering properties of LFC reinforced with coconut fibre and polyvinyl alcohol fibre. They found that FC strengthened with coconut fibre performs better than with polyvinyl alcohol fibre. It should be pointed out that AF is a high-strength natural fibre that can easily be combined with cotton fibre or other synthetic fibres to create blended fabrics and textiles [16]. AF is also used in high-quality paper, agricultural production of package material, towing ropes for vehicles, wet drilling cords, etc. [17]. However, AF is often disposed of as cultivated waste. Numerous programmes focused on the lower cost of materials have been proposed despite the critical demand for the production of green concrete and affordable housing for people living in Malaysia [18, 19]. Hence, the cultivated waste is recommended to be utilized as a complete replacement for building materials [20, 21, 22]. The AF has the potential to improve the strength and mechanical properties of LFC [23, 24]. There are many published studies of the applications and further research of AF these days in concrete based materials. In this matter, there are efforts to research new and stronger fibres that enhance the concrete strength and durability. It is essential to understand that AF can enhance the strength and durability of concrete [25]. Despite that, some issues need to be addressed, such as the level of concrete improvement and capability of AF depending on the ratio of the fibres to take force from flexural, compression and tensile strength [26]. From the above review, the influence of AF inclusion in LFC for mechanical properties improvement is not well explored and understood. Therefore, this study focuses on determining the mechanical properties of LFC reinforced with AF. Consequently, this study makes an effort to uncover the potential utilization of AF in cement-based materials.

2. MATERIALS AND DESIGN

2.1. Cement

One of the fundamental components of concrete is cement. It has been used as a binder in concrete, mortar, and other construction material. Concrete is made up by mixing the cement with fine aggregate and other admixtures such as AF until a hardening paste is formed. Cement is usually made from a chemical mixture such as silica, calcium, and other minerals. Cement is an important material with cohesive and adhesive properties capable of producing utterly compact mixing particles. The cement was purchased under the brand of "Castle" which fulfils the requirements stated in BS 196 [27]. The cement used in this research is Type 1. Type I is a general-purpose portland cement suitable for all applications where the special properties of other types are not necessary. It is used where cement or concrete is not subject to specific exposures, such as sulfate attack from soil or water, or to an objectionable temperature rise due to heat generated by hydration.

2.2. Sand

Fine aggregate is generally natural sand. The fine aggregate needs to pass a 9.5 mm sieve, while the required size of fine aggregate should be not exceeded 2 mm to achieve the desired properties of LFC as per the BS 882 [28] recommendations. Regarding this matter, this research utilized fine aggregate with a fineness modulus of 1.4 and a specific gravity of 2.7 as a constituent material in mortar mixes. After the fine aggregate was sieved, they were kept in a clean container until they were set to be mixed.

2.3. Water

Generally, clean tap water was used in the mixture. However, if the water contains any chemical compounds, the efficiency of cement and aggregate can be affected. To ensure that an LFC possesses the required strength, durability and efficiency, an appropriate amount of water needs to be considered; during the mix, the hydration process will trigger the chemical bonding of cementitious content. An appropriate value of water is determined by the cement used in the mix. This research used the water-cement ratio of 0.45 since it will achieve the desired workability.

2.4. Foaming agent

The protein-based surfactant (Noraite PA1) was chosen due to its high efficiency, potency, and dense cell bubble structure. This foaming agent capacity must determine using ASTM C869-91 [29] and ASTM C796 [30] for the test procedure. The production of foam uses a generator which is Portafoam PA-1. This machine is supplied with a digital timer that allows setting the flow rate acts where it converts the liquid chemical into foam. The Noraite PA1 can generate stable foam with a density of 55–70 kg/litre. This mixture can create 30 litres of foam.

2.5. Abaca fibre

Abaca is often disposed of with other agricultural wastes. The usage of AF in concrete can produce a clean, environmentally friendly, and reasonable price housing system in Malaysia. Thus, agricultural wastes can be used in place of or in addition to conventional construction material. The AF (plant of the family Musaceae) used in this research was supplied by DRN Technologies Sdn Bhd. This research is using various percentages of AF (0.15%, 0.3%, 0.45% and 0.6%) as an admixture in LFC. Fig. 1 shows the raw AF was weighed before mixing with the LFC base mix.

Figure 1.
The AF was weighed before mixing with LFC

Tables 1, 2 and 3 demonstrate the chemical composition, physical attributes and mechanical properties of AF correspondingly. AF had superior cellulose proportion which may support considerably when in composite action with LFC cement matrix. Natural fibres with superior cellulose substance, usually, exhibit a low deformation with an excellent modulus of elasticity [31] and this is verified by the experimental data accomplished in their study. Moreover, it was testified that generally, the modulus of elasticity and tensile strength of plant fibre rises with a rising cellulose substance of AF.

Table 1.
Chemical composition of AF

Composition	%, dry weight
Cellulose (%)	41.1
Lignin (%)	21.2
Hemicellulose (%)	28.5
Ash (%)	2.3
Extractives (%)	3.9
Moisture (%)	2.6

Table 2.
Physical properties of AF

Component	Properties
Length of fibre	20 mm
Diameter of fibre	275 um
Width of lumen	16.38 um
Density of fibre	0.79 g/cm^3
Angle of fibril (°)	41
Runkel ratio	0.266

Table 3.
Mechanical properties of AF

Component	Properties
Modulus of elasticity (MPa)	14978
Tensile strength (MPa)	149.2
Elongation at break (%)	10.89

2.6. Mix Design

To conduct the experiment in the current study, a total of 5 mixes were prepared. Table 4 shows the mixture design proportions of 550 kg/m^3 density. It is crucial to remember that AF was used as an additive at concentrations ranging from 0.15%, 0.30%,0.45% and 0.60% by weight of the total mix in this analysis. As previously stated, the mortar was composed of cement, sand, and water in a ratio of 1:1.5:0.45.

2.7. Curing method

Properly cured LFC has better surface hardness and can better withstand surface wear and abrasion. Curing also makes LFC more impermeable, which prevents moisture and water-borne chemicals from entering the LFC, thereby increasing durability and service life. It is essential to understand that a reduced amount of water in LFC will result in volatile temperatures. This will lead to a crack on the surface of LFC. After the specimens are demoulded, they were placed in a plastic wrap and securely tied and

Table 4.
Mix design proportion

Sample	Density (kg/m^3)	Abaca fibre (kg)	Cement (kg)	Sand (kg)	Water (kg)
Control	550	0.000	16.91	25.36	7.61
0.15% AF	550	0.074	16.91	25.36	7.61
0.30% AF	550	0.149	16.91	25.36	7.61
0.45% AF	550	0.224	16.91	25.36	7.61
0.60% AF	550	0.299	16.91	25.36	7.61

splashed with water to maintain the moist condition (Fig. 2). Following that, each of the specimens were removed from the plastic wrap on each testing day (day-7, day-28 and day-56) and ready for testing. Meanwhile, the specimens were dried for 24 hours at 100±5°C in the oven and then ready for compression, flexural and splitting tensile strength tests.

Figure 2.
Process of wrapping of LFC specimens during the curing stage

3. EXPERIMENTAL SETUP

3.1. Compression Test

This test was performed using a GT-7001-BS300 universal testing machine with a 300 kN size as shown in Fig. 3. This test follows BS 12390-3 [32] using a cubic sample of 100 mm × 100 mm × 100 mm in size. Meanwhile, the axial compressive load acted on specimens at a rate of 0.2 N/sec before the failure occurred. The result was obtained, and the test was conducted on day-7, day-28 and day-56. The average compressive strength is determined using the 3 specimens. The calculation of compressive strength is as follows:

$$\text{Compressive strength} = \frac{\text{breaking load}}{\text{area}} \qquad (1)$$

Figure 3.
Setup of compression test

3.2. Flexural test

In this research, a rectangular beam of 100mm x 100 mm x 500 mm was used to establish the LFC flexural strength shown in Fig. 4. The test was carried out according to BS EN 12390-5 [33]. The machine that aided in this test program is Go-Tech GT-7001-C10 which is a universal testing machine. The support's nominal distance was 300 mm, and the roller is let for free horizontal movement. The LFC has applied a constant load of 0.2 N/sec. The result was obtained, and the tests were conducted on the 7th, 28th and 56th. The average flexural strength is determined using three specimens. The flexural strength is determined using the equation as below:

$$\sigma f = \frac{3PL}{2bd^2} \quad (2)$$

where,
F – flexural strength
P – bending broken force
L – span
B – width of the prism
D – thickness of the prism

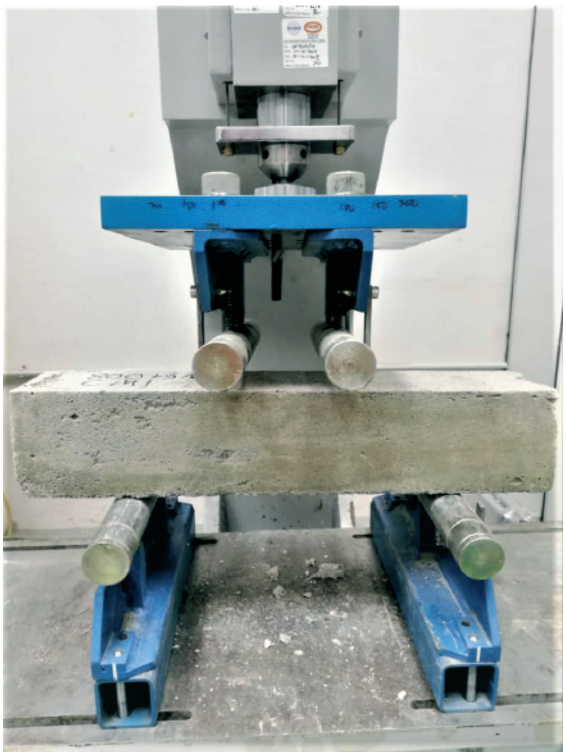

Figure 4.
Setup of flexural test

3.3. Splitting tensile test

This test aims to ascertain the load under which LFC begins to fail. It is a phenomenon known as tensile collapse. This test is using BS EN 12390-6 [34] as a guide. The setup of splitting tensile strength is shown in Fig. 5. The diameter and height of the specimens are 100 mm and 200 mm, respectively. The machine that is used is GOTECH GT 7001-BS300 which is a universal testing machine. The specimens are subjected to 0.2 N/sec before the result was obtained. The test was conducted on the 7th, 28th and 56th. The average flexural strength is determined using three specimens. Splitting tensile strength is determined using the equation as follows:

$$T = \frac{2P}{\pi LD} \quad (3)$$

where,
T – splitting tensile strength
P – maximum load
L – length of the specimen

Figure 5.
Setup of splitting tensile test

Table 5 summarized the details of the LFC specimens, types of tests, the number of specimens and standard codes referred to in these mechanical properties tests.

Table 5.
Mechanical properties tests

Type of Test	Specimen	Testing day	No. of specimens (each mix)	Standard
Compression test	Cube (100 mm × 100 mm × 100 mm)	7th, 28th and 56th	9	BS EN 12390-3
Flexural test	Prism (100 mm × 100 mm × 500 mm)	7th, 28th and 56th	9	BS EN 12390-5
Splitting tensile test	Cylinder (100 mm dia. × 200 mm)	7th, 28th and 56th	9	BS EN 12390-6

4. RESULTS AND DISCUSSION

4.1. Compressive strength

A compressive strength test was conducted in this research to identify the ability of LFC to resist the load that is applied to it. This test can determine the performance of mechanical properties of the LFC according to ASTM C39. Fig. 6 below depicts the result of compression strength of LFC with a density of 550 kg/m^3. The results show an increasing trend from day-7 until day-56 with AF in the LFC. When 0.15% AF was added to LFC, the growth rate of the compressive strength compared to the control specimen is not obvious. This is because the AF content is so little that it only has a weak delaying and constraining effect on LFC cracks, and the macro expression is that the development of compressive strength is not substantial. The highest compressive strength achieved is 1.71 N/mm^2 on day-56 with the inclusion of 0.45% AF; meanwhile, the lowest compressive strength is 0.87 N/mm^2 on day-7 which is the control mix. Moreover, the compressive strength value on day 7 showed slight increases from 0.87 N/mm^2 with the control mix to 1.34 N/mm^2 with 0.45% AF. After that, it decreased to 1.12 N/mm^2 0.6% in addition to AF in LFC. On day-28, the compressive strength increases from 1.05 N/mm^2 with control mix until 1.5 N/mm^2 with 0.45% AF and decreases until 1.26 N/mm^2 with 0.6% AF. This result also shows the increasing trend of compressive strength on day-56, which starts from 1.18 N/mm^2 on the control mix until 1.71 N/mm^2 with 0.45% of AF and starts to decrease at 1.26 N/mm^2 with 0.6% of AF. LFC has lower compressive strength according to the control mix's result in the graph. A higher amount of foam creates a higher amount of air voids and lowers the density. Moreover, the age of concrete also influenced the compressive strength value of LFC. The longer the testing age, the higher the compressive strength of the LFC, as can be seen in the comparison between day-7 and day-56 according to the graph. This weakness can be improved with the addition of AF as shown in the result. AF can control the crack on LFC, and it can strengthen the bonding between the matrixes [35]. Hence, it can be concluded that AF contributes to the enhancement of the compressive strength of LFC at a maximum weight fraction of 0.45%. At this optimum weight fraction of 0.45%, the random dispersal of AF in the LFC matrix forms a network structure, which creates a common stress framework with the LFC matrix. When the LFC is subjected to axial compressive load and generates microscopic cracks, the stress is transmitted from the LFC cementitious matrix to the AF between the cracks due to the bond force between the AF and the LFC. And the AF consumes energy in the process of deformation and pulling out so that the microscopic cracks of the LFC were delayed and inhibited [36]. Beyond the optimum level of AF, agglomeration and the non-uniformity dispersion of BFF were seen, which results in a drop in compressive strength (at 0.45% weight fraction of AF). Additionally, when the AF content in LFC is too high, the distance between each AF is lessened or even the AF contacts [37]. Furthermore, the bond between the AF and the LFC matrix cannot completely work, and the bond effect is decreased. If the AF content is too high or the AF is not evenly dispersed in the LFC matrix, the compressive strength of concrete will be adversely impacted. Moreover, the high amount of AF in FC will retard the process of hydration hence leading to low compressive strength [38]. Considering that the LFC matrix has numerous voids of varying size and shape and the presence of micro-cracks at the transition area between matrices, using AF fibre facilitates regulating failure characteristics when subjected to compressive loads [39].

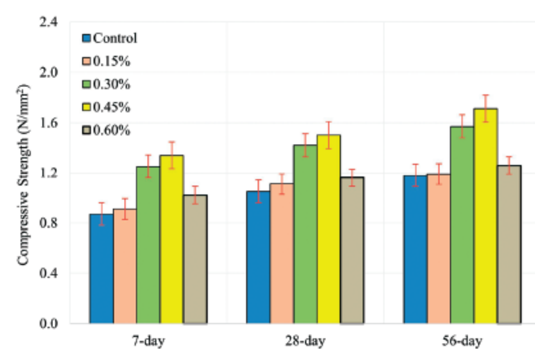

Figure 6.
Compressive strength of LFC with different weight fractions of AF

4.2. Flexural strength

Flexural strength is the ability of the material to withstand bending forces applied perpendicular to its longitudinal axis. Fig. 7 exhibits the flexural strength of 550kg/m^3 of LFC in addition to various percentages of AF. The result presented in Fig. 7 shows that the highest value of flexural strength is 0.61 N/mm^2 on day-56 with the inclusion of 0.45% AF; meanwhile, the lowest value of flexural strength is 0.2 N/mm^2 on day-7 with the control mix specimen. The result of flexural strength climbed from 0.20 N/mm^2 with control mix to 0.37 N/mm^2 with 0.45% AF on day-7 and started to decrease at 0.6% AF, 0.23 N/mm^2. In addition, on day-28 and day-56, the result shows an increment from 0.23 N/mm^2 to 0.46 N/mm^2 and 0.27 N/mm^2 to 0.51 N/mm^2, respectively with addition of 0.15%, 0.35% and 45% AF. However, the LFC with 0.60% AF decreased to 0.28 N/mm^2 and 0.36 N/mm^2 on day-28 and day 56. This can be explained by AF which might be failed to fill the matrix. This decreased trend has occurred at a certain amount of AF on day-7, day-28, and day-56. LFC has a lower ratio of flexural to compressive strength, ranging between 0.2 to 0.4 compared to standard concrete. However, with the addition of AF, the flexural strength has been improved because it can change the character of the material from being brittle to ductile. It should be pointed out that the plastic zone of the LFC during flexural resistance improves remarkably after adding AF, and the plastic zone of the LFC improves with the increase of the AF content up to the optimum weight fraction [40]. The reason is that the flexural stress at the crack can be transmitted from the LFC matrix to the AF and then to the LFC matrix at the other end of the AF after the AF is integrated into the LFC. In the process of transferring stress, the AF will deform and pull out to some extent, which consumes part of the energy, thus impeding and preventing the crack of LFC. Stress is slowly transmitted from the middle of the prism to both ends of the prism, which permits the plastic zone of the prism to expand to both ends [41]. However, disproportionate AF inclusion of more than causing weight fractions to exceed 0.45% led to lower cohesion between AF and the cementitious matrix [42]. Besides, it will also decrease the spacing between the AF and even cause the AF to contact each other and reunite. When the bond between the AF and the LFC matrix is reduced, so the flexural strength is diminished [43]. An AF weight fraction of 0.45% is ideal for LFC because flexural and compressive strengths are more desirable.

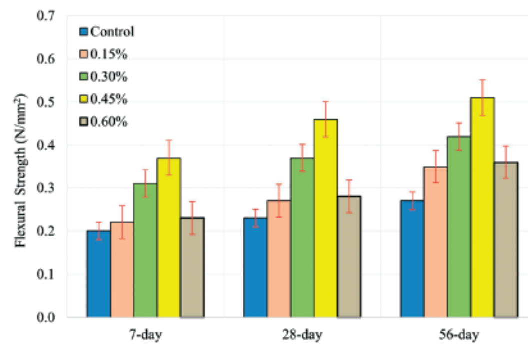

Figure 7.
Flexural strength of LFC with different weight fractions of AF

4.3. Splitting tensile strength

Fig. 8 shows the splitting tensile strength of LFC with a density of 550 kg/m^3. The test was held on three different days, on 7, 28 and 56 days. Overall, it is observed that LFC having any weight fractions of AF displays improved splitting tensile strength compared to unreinforced LFC (control specimen). This may occur due to the superior tensile strength of the AF (refer to Table 3). The AF are distributed randomly into the LFC mixture. The AF is oriented in the progressing crack's perpendicular direction, which can take tensile stress and help increase the crack arresting capability or bridging effect in LFC. Besides, the existence of AF can make the LFC more ductile, and the tensile capacity is commonly greater for a ductile material than that of brittle material [44]. Based on the graph, day-56 has the highest splitting tensile strength value, 0.36 N/mm^2 with 0.45% AF, while day-7 has the lowest reading of splitting tensile strength, 0.12 N/mm^2 with the control specimen. The LFC with the inclusion of AF has an increasing reading of splitting tensile strength from 0.14 N/mm^2 to 0.25 N/mm^2 on day 7. The trend is same with day-28 and day-56 with 0.18 N/mm^2 to 0.31 N/mm^2 and 0.24 N/mm^2 to 0.36 N/mm^2, respectively. However, it starts to decrease on each test day when the AF exceeds 0.45% in LFC with readings of 0.14 N/mm^2, 0.22 N/mm^2 and 0.26 N/mm^2. This situation happened also with compressive strength and flexural strength. However, the addition of AF in LFC successfully acted as the anchor that holds the matrix together, which helped to improve the splitting tensile strength. No macro crack is envisaged on the surface of the LFC. As no spalling has transpired in the LFC, it can take the extra tensile load before fracture by providing a ductile behaviour. Othuman Mydin et al. [45] reported that the natural fibre length between 19–25 mm could cross both sides of LFC cracks and create a strong bridging between the cracking interfaces. Overall, LFC containing fibres indicates greater ductility than LFC without fibre. Fibre delays the first crack formation across the crack and retards visible cracking. Beyond the optimum level of AF addition, accumulation and the non-regularity spreading of AF were detected, which results in the decline of the tensile strength (starting from 0.60% weight fraction of AF). Splitting tensile strength improved because of higher LFC robustness facilitated by AF. Adding 0.45% fibre enhances LFC tensile strength by enhancing ideal pozzolanic interactions with cement, producing high-density LFC. This implies that the inclusion of AF improves the splitting tensile strength of LFC (all weight fractions tested in this study). The elongation at break of single AF was considered minimal, resulting in exceptional splitting tensile strength when added into LFC. It should be pointed out that the enhancement in splitting tensile strength of LFC is due to the reduction in the formation and development of micro-cracks for distributing comparatively stiffer AF randomly into the LFC mixture. These randomly oriented AF can control the crack propagation and reduce the width of cracks. The cracks will initiate and start to propagate with increasing the tensile stress [46]. When the cracks reach the LFC matrix-AF interfaces, the AF takes additional stress, and the further propagation of cracks is resisted. Besides, the higher hardness and the higher cohesive force of AF produce a strong network skeleton inside the LFC

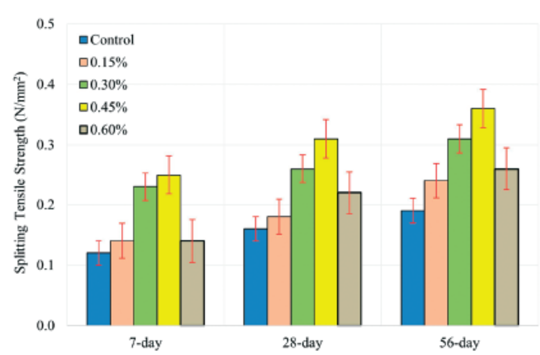

Figure 8.
Splitting tensile strength of LFC with different weight fractions of AF

4.4. Compressive and flexural strengths relationship

Fig. 9 illustrates the correlation between the compressive strength and flexural strength of LFC with a density of 550 kg/m^3. From the figures, the result of compressive strength and flexural strength scatters and the linear line to illustrate the connection between them. The value of R^2 shows the relationship between both results of the LFC, when the R2 is close to the value of 1 that means is the best indication that explained the correlation between compressive strength and flexural strength. The density of LFC influences each strength. It can be noted that LFC such as 550 kg/m^3 reduces the strength of compression and flexural due to the significant number of voids. It can be observed from the graph, the age of the LFC also influenced its strength of the LFC. In addition, the inclusion of AF also helped to strengthen the compressive strength and flexural strength; as it can be seen, the LFC started to increase with 0.15% AF compared to the control specimen. This is because AF can bond with the matrix, reducing the void in the LFC.

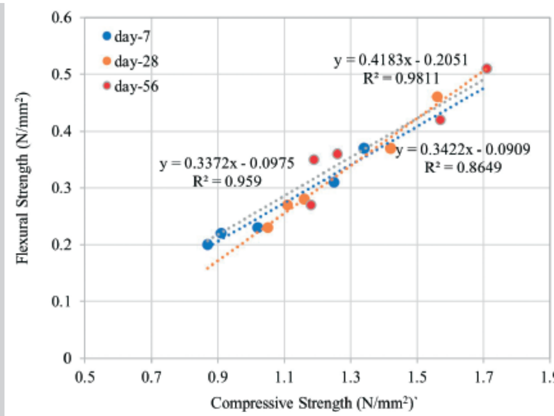

Figure 9.
Relationship between compressive strength and flexural strength of LFC

4.5. Compressive and tensile strengths relationship

Fig. 10 reveals the association between compressive and tensile strengths for 550 kg/m^3, including a variable percentage of AF. The graph demonstrates the R2 value for the linear line through the data, which indicates the correlation between compressive and tensile strengths. The R^2 of this correlation for each testing day of 7, 28, and 56 days is 0.90, 0.93, and 0.95. respectively. The value of R^2, which is close to the one, is illustrated by how closely the compressive strength and tensile strength are.

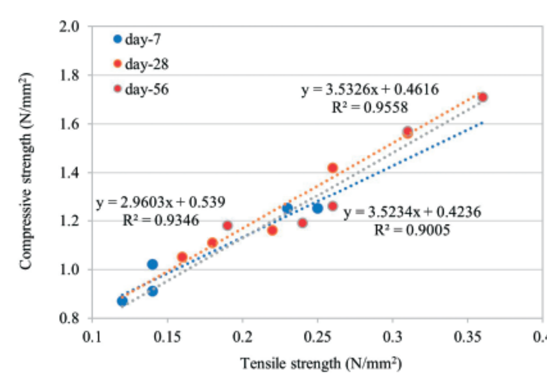

Figure 10.
Relationship between compressive and tensile strengths of LFC

5. CONCLUSIONS

In this experimental research, the LFC mechanical properties with the addition of various amounts of raw abaca fibre (AF) into 550 kg/m^3 density LFC were performed. Five different proportions of AF were added i.e. 0.00%, 0.15%, 0.30%, 0.45% and 0.60%. From the results achieved in this experiment, it can be summarized that the compressive, flexural and tensile strengths of LFC are enhanced with the inclusion of AF. Though, the different percentages of AF included in LFC gave a different results on the mechanical properties of LFC. Overall, 0.45% of AF in LFC gave an outstanding flexural strength, compressive strength and splitting tensile strength compared to other percentages considered in this study. AF-matrix boundary bonding, which is deemed as a coarser surface, is beneficial given its surface roughness. Consequently, it inspires the AF fibre, and matrix mechanical interlocking, thus enhancing the mechanical properties of LFC.

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