Transactions on Science and Technology Vol. 9, No. 2, 26 - 34, 2022

Properties of Lightweight Foamcrete Strengthened With Cellulose Fibre Isolated From Oil Palm Frond

Md Azree Othuman Mydin
School of Housing, Building and Planning, Universiti Sains Malaysia, 11900, Penang, MALAYSIA.
E-Mail: azree@usm.my; Tel: +604-653 2507; Fax: +604-658 9666.

ABSTRACT This study concentrates on a laboratory assessment to evaluate the efficiency of adding cellulose fibre isolated from an oil palm bark in lightweight foamcrete (LF) to improve the strength properties. LF samples were strengthened with 0.1%, 0.2%, 0.3%, and 0.4% volume fractions of cellulose frond fibre (CFF). There were three low densities of LF were considered, namely 500 kg/m^3, 750 kg/m^3, and 1000 kg/m^3. The parameters investigated were compressive, splitting tensile and bending strengths. The results indicated that the presence of 0.3% CFF in LF helped to obtain the highest results for bending, compressive and splitting tensile strengths. CFF acts as a space filler and bridges the gaps and microcracks in LF, resulting in high strength. In addition, CFF helped to inhibit the micro-cracks propagation in the plastic state of LF. This study provided vital experimental data to assist future researchers in the field of LF in utilizing natural fibers to enhance the properties of LF.

KEYWORDS: Foamcrete; Strength Properties; Compression; Bending; Tensile
Received 2 May 2022 **Revised** 15 May 2022 **Accepted** 2 June 2022 **In press** 21 June 2022 **Online** 8 July 2022

Original Article

INTRODUCTION

Recently, researchers from all over the world have been focusing on the development of green concrete for building materials that are lightweight, durable, easy to use and economical (Elrahman *et al*., 2019; Munir *et al*., 2015). With the growth of research for sustainable building materials used in buildings, the technological advancements in this area have progressively accelerated. One of the most significant ideas is the procurement and application of non-conventional local building materials, involving the possibility of utilizing various cultivated wastes as construction materials (Zhu *et al*., 2018). Natural strengthening materials can be acquired at a cheaper price and energy using regional labor and technologies. The application of natural fibers is of particular importance to less developed regions where traditional building materials are not easily accessible or are too costly (Serri *et al*., 2014). Lightweight foamcrete (LF) has been predominantly employed as a filler substance in construction. Nevertheless, its outstanding thermal properties and fire resistance performance signify its great potential as a construction material (Sari & Sani, 2017). LF made from ordinary Portland cement (OPC) has several properties: it is excellent under compression but low in tension and tends to be fragile. The tensile vulnerability can be overcome by conventional steel fortification and, to some extent, by integrating an adequate number of specific fibers. The application of fibers also modifies the performance of the fiber-matrix composite after failure, increasing its stiffness (Hamad, 2014). LF can be specified as a material comprising at least 10% by volume of mechanically formed moisture in the slurry of mortar, in which air voids are fixed in the matrix using a suitable surfactant. LF can be produced by introducing a foaming agent into a cement-based mortar. The surfactant of different types can be included, and the foam is produced by gentle but thorough mixing. On the other hand, the surfactant can be aerated before it is employed (Castillo-Lara *et al*., 2020). However, in recent years, there is a growing concern about the use of LF as semi-structural material in buildings (Hanizam & Ahmad, 2014). LF is known to be a relatively fragile material under typical stresses and impact loads. Because of these properties, LF, in the past LF structural members have been strengthened with fortifying bars to resist tensile strains. Even though the presence of steel reinforcement substantially enhances the LF strength, the growth of microcracks should be properly controlled to create concrete with homogeneous tensile properties (Fu *et al.*, 2013).

In Malaysia, oil palm is one of the most important trades that has contributed to the development of the economy (Mohammadhosseini *et al.*, 2016). Oil palm empty bunch, frond, and shell from palm oil mills are included in this classification. However, given the presence and volume of oil palm waste, major landfill problems arise. To solve the problem of biomass waste, oil palm by-product waste can be used as filler material in LF to expand its durability and mechanical performances (Momeen *et al.*, 2016). LF is a porous cemented material obtained by introducing preformed foam into the cement matrix. The combination of these materials results in air voids that form in the underlying microstructure of the material (Mahzabin *et al.*, 2018). These fibers are replacing other conventional additives such as glass and steel fibers, which have been used extensively. This shift in trend is due to the added value that fibers offer to these materials, particularly in terms of sustainability. Therefore, this study attempts to investigate the potential use of CFF from the oil palm industry in LF to improve the compressive, bending, and splitting tensile strengths of LF. The addition of natural cellulose fibers in LF is expected to improve the bond between cementitious composites. The addition of cellulose fibers in small amounts can reduce the effects of early aging on the LF durability properties (Klyuev *et al.*, 2018). It can also prevent the formation of cracks under load. Natural fiber strengthened LF has many advantages, such as being lightweight, low cost, durability, and high stiffness.

METHODOLOGY

Material Preparation

Cement, sand, foaming agent and water are the primary materials employed to make LF. Portland cement according to British Standard BS-12 (BS-12, 1996) was used and a handy foam generator was utilized to generate the foam. In this evaluation, a synthetic surfactant was utilized to produce the foam. Also, fine sand was used, which was acquired from a regional supplier. The appropriate size of the fine sand applied was 1.19 mm and was sieved with a sieve machine in accordance with BS-882 (BS-882, 1992). Tap water which was free from impurities was used. The water to cement ratio was set at 0. 5. The cellulose fibers (CFF) used in this study were collected from a local farm, and processed into 17mm CFF by a mechanical refining process. The percentage by weight of OPSF used was 0.1%, 0.2%, 0.3% and 0.4% of the total volume of the blend, respectively. Tables 1, 2 and 3 demonstrate the physical properties, chemical structure, and mechanical properties of the CFF, in that order.

Table 1. Physical properties of cellulose frond fiber

Element	Properties
Diameter	21.9 um
Density	0.58 g/cm^3
Length	20mm
Lumen Width	14.8 um
Fibril Angle (°)	41
Runkel ratio	0.19

Table 2. Chemical composition of cellulose frond fiber

Composition	%, dry weight
Hemicellulose	14.9
Cellulose	27.2
Glucose	21.8
Lignin	25.3
Ash	1.3
Xylose	9.5

Table 3. Mechanical properties of cellulose frond fiber

Element	Properties
Modulus of elasticity	4.98 GPa
Elongation at break	12.1%
Tensile strength	76.8 MPa

Mix Design

For this study, 15 mixtures were prepared. The density selected was 500, 750 and 1000 kg/m^3. The weight percentage of CFF was 0.1%, 0.2%, 0.3% and 0.4%. For all LF mixes, the sand-cement proportion was set at 1:2 and the water-cement proportion at 0.5. The mix ratios considered in this study is shown in Figure 4.

Table 4. Mix proportions

Specimen	Mix Density (kg/m^3)	Mix Ratio (s:c:w)	Cement (kg)	Fine sand (kg)	Water (kg)	CFF (kg)
0.0% CFF	500	1:2:0.5	16.36	32.72	8.18	0.000
0.1% CFF	500	1:2:0.5	16.36	32.72	8.18	0.062
0.2% CFF	500	1:2:0.5	16.36	32.72	8.18	0.124
0.3% CFF	500	1:2:0.5	16.36	32.72	8.18	0.186
0.4% CFF	500	1:2:0.5	16.36	32.72	8.18	0.248
0.0% CFF	750	1:2:0.5	23.97	47.94	11.99	0.000
0.1% CFF	750	1:2:0.5	23.97	47.94	11.99	0.088
0.2% CFF	750	1:2:0.5	23.97	47.94	11.99	0.175
0.3% CFF	750	1:2:0.5	23.97	47.94	11.99	0.263
0.4% CFF	750	1:2:0.5	23.97	47.94	11.99	0.351
0.0% CFF	1000	1:2:0.5	31.58	63.16	15.79	0.000
0.1% CFF	1000	1:2:0.5	31.58	63.16	15.79	0.114
0.2% CFF	1000	1:2:0.5	31.58	63.16	15.79	0.227
0.3% CFF	1000	1:2:0.5	31.58	63.16	15.79	0.341
0.4% CFF	1000	1:2:0.5	31.58	63.16	15.79	0.454

Experimental setup

The compression test was accomplished in line with BS12390-3 (BS 12390, 2011). The LF sample size was a cube of 100 x 100 x 100 mm in size. The upper limit load and compressive strength were documented. Next, the bending test was executed in compliance with ASTM C-293 (ASTM C-293, 2016). The specimen size was a prism of 100 mm x 100 mm x 500 in size to ascertain the bending stress. Following, the splitting tensile strength test of LF was completed in compliance with ASTM C-496 (ASTM C-496, 2017). The LF sample size was a cylinder of 100mm in diameter and 200mm in height.

RESULTS AND DISCUSSION

Compressive Strength

The compressive strength for the entire densities studied was shown in Fig. 1, Fig. 2, and Fig. 3. From these figures, it can be seen that the addition of CFF in LF improved the compressive strength regardless of the volume fraction. The tests after 7, 28, and 56 days of curing showed that the mixes had higher compressive strength in comparison to the control sample for all densities. The ideal volume fraction of CFF was 0.3%. The highest compressive strengths accomplished at day-56 were 1.56 MPa, 2.61 MPa, and 3.96 MPa at a volume fraction of 0.3% CFF for densities of 500 kg/m^3, 750 kg/m^3, and 1000 kg/m^3, respectively, compared to the control sample, which had compressive strengths of only 1.14 MPa (500 kg/m^3), 1.99 MPa (750 kg/m^3), and 3.12 MPa (1000 kg/m^3). Beyond the optimal CFF content, non-uniform distribution and agglomeration of CFF were observed, resulting in a decrease in compressive strength (at a volume fraction of 0.48% of CFF). The high content of CFF in LF delays the process of hydration and thus leads to low compressive strength (Savastano *et al.*, 2000). Since LF has voids of various shapes and sizes in the LF matrix and microcracks in the transition zone amongst the matrix, the presence of CFF fibers contributes to the failure of the material.

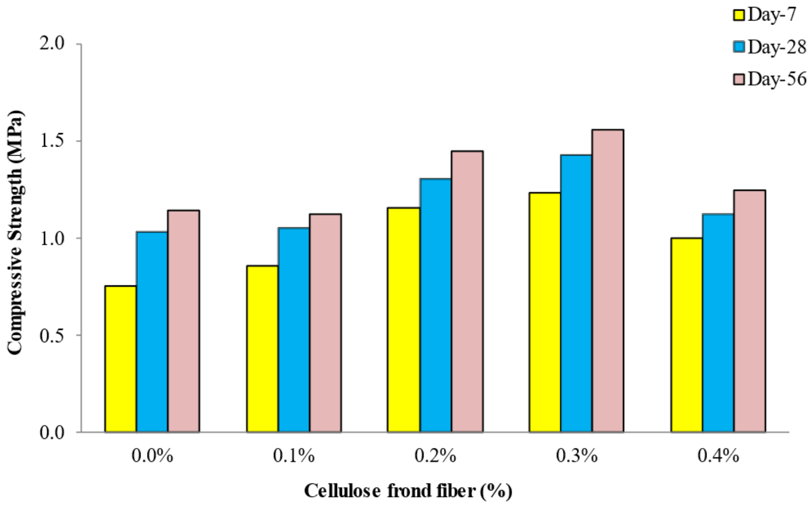

Figure 1. Compressive strength of 500 kg/m^3 density LF with different weight fractions of CFF

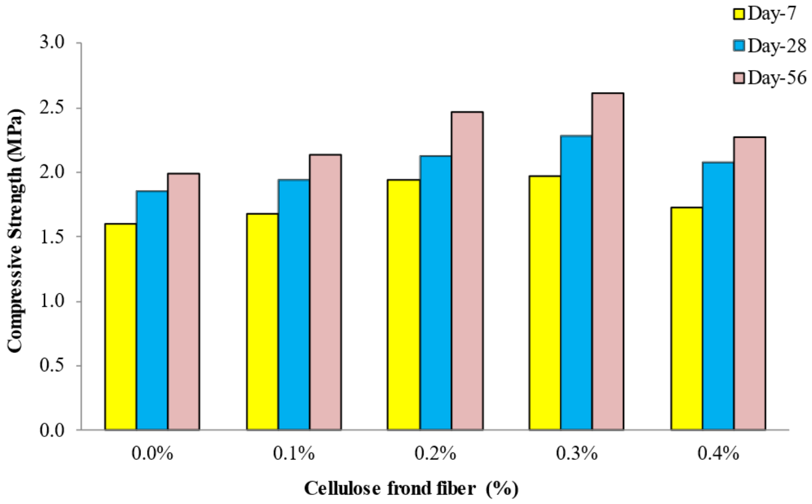

Figure 2. Compressive strength of 750 kg/m^3 density LF with different weight fractions of CFF

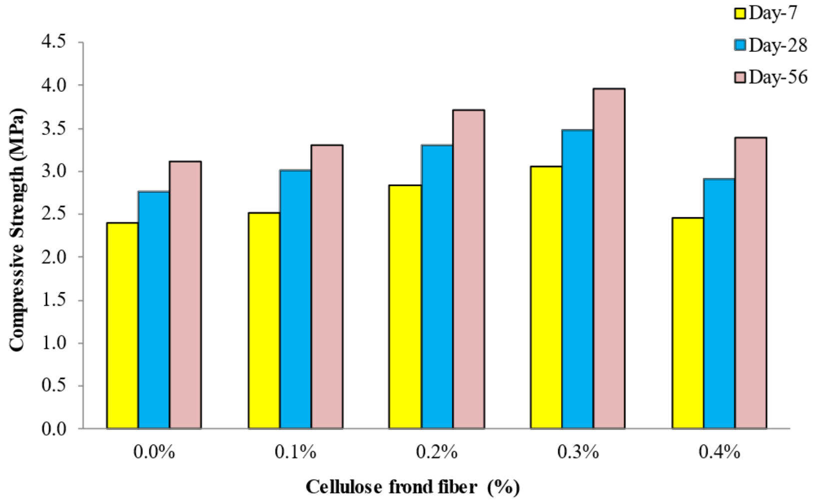

Figure 3. Compressive strength of 1000 kg/m³ density LF with different weight fractions of CFF

Bending Strength

The bending strength of LF with the insertion of CFF boosted for all densities despite the volume fraction of CFF in LF. The results of bending strength obtained for densities 500, 750, and 1000 kg/m³, respectively were shown in Fig. 4, Fig. 5, and Fig. 6. The control specimen obtained the lowest bending strength, which increased insignificantly with test age. However, the specimens from LF with the presence of CFF showed a substantial increase in bending strength with age. On day-28, the control sample bending strength was 0.23 MPa, 0.45 MPa, and 0.57 MPa for densities 500, 750, and 1000 kg/m³, respectively, in that order. The optimum volume fraction of CFF that gave the best results of bending strength was 0.36%. The highest bending strengths obtained on day 56 were 0.50 MPa, 0.78 MPa, and 1.20 MPa with a volume fraction of 0.3% of CFF for densities of 500, 750, and 1000 kg/m³, respectively. The incorporation of CFF in LF plays an important role in improving the LF matrix and changing the material properties from brittle to ductile state. CFF increases the bending strength for entire densities. However, too high a weight fraction of FBB fibers in LF (more than 0.36%) resulted in a reduction of the bond between the fibers and cement matrix. The use of a volume fraction of 0.36% of CFF can be considered an optimum percentage for LF. The increase in bending strength matches well with the compressive strength enhancement. The high bending strength accomplished is attributable to the decrease of porosity in LF (Ketty *et al.*, 2007).

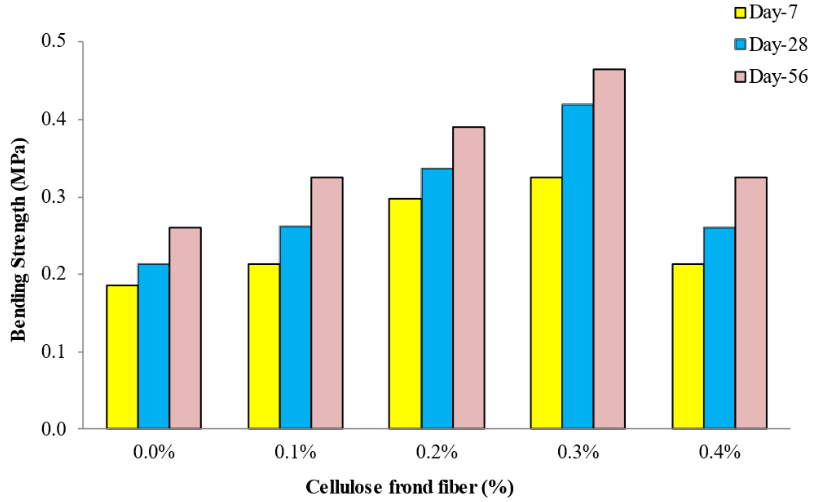

Figure 4. Bending strength of 500 kg/m³ density LF with different weight fractions of CFF

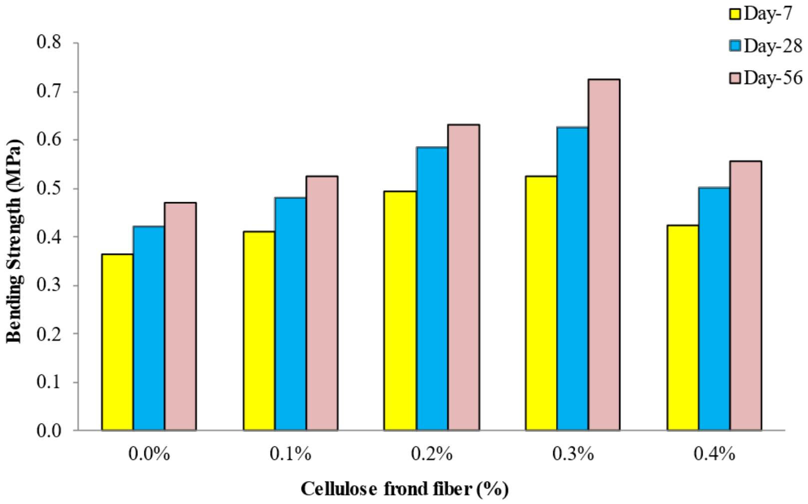

Figure 5. Bending strength of 750 kg/m³ density LF with different weight fractions of CFF

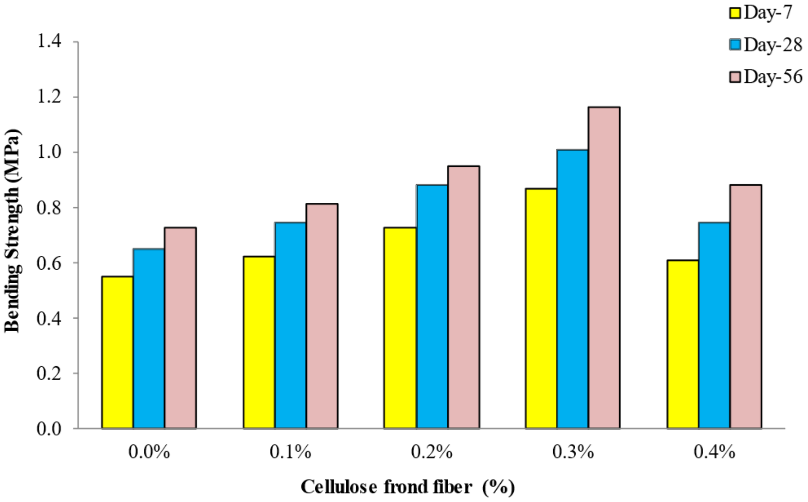

Figure 6. Bending strength of 1000 kg/m³ density LF with different weight fractions of CFF

Splitting Tensile strength

The splitting tensile strength results for the entire densities considered in this study were shown in Fig. 7, Fig. 8 and Fig. 9. The same tendency was observed, where the presence of 0.3% by weight of CFF gave the optimal splitting tensile strength. The uppermost splitting tensile strengths obtained at day-56 were 0.48 MPa, 0.52 MPa, and 0.79 MPa at 0.3% CFF by weight for densities 500 kg/m3, 750 kg/m3, and 1000 kg/m3, respectively, compared to the control specimen, which achieved splitting tensile strengths of only 0.28 MPa (500 kg/m³), 0.30 MPa (750 kg/m³), and 0.45 MPa (1000 kg/m³).

Beyond the ideal level of CFF incorporation, accumulation and irregular distribution of CFF were observed, leading to a decrease in splitting tensile strength (from 0.3% by weight of CFF). The improvement in splitting tensile strength is caused by the raise in toughness of LF due to the existence of CFF fibers. The addition of 0.3% of fiber enhances the LF splitting tensile strength, by promoting the ultimate pozzolanic response with the cement thus producing a denser LF. This entails that the existence of CFF augments the splitting tensile strength of LF irrespective of the volume fraction of CFF (Momeen *et al.*, 2016). The CFF elongation at break was found to be marginal, resulting in excellent splitting tensile strength when included in LF.

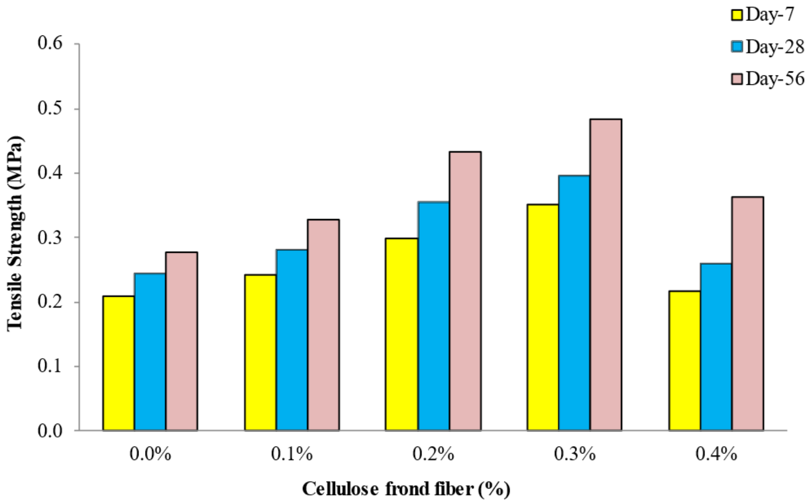

Figure 7. Splitting tensile strength of 500 kg/m³ density LF with different weight fractions of CFF

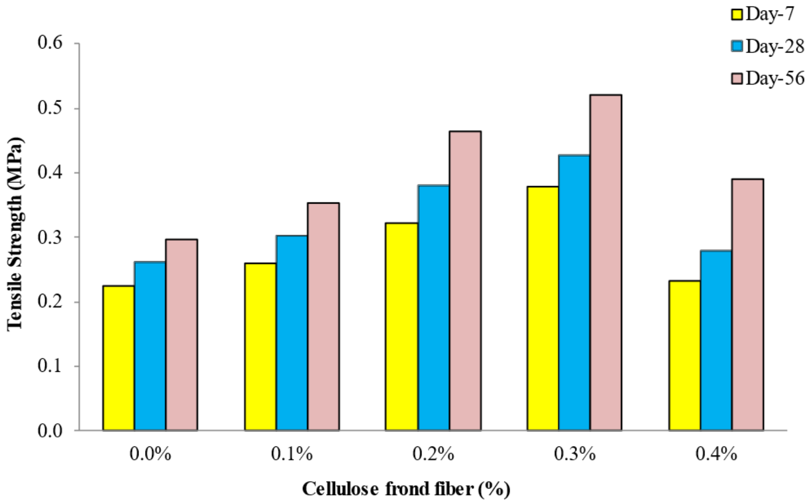

Figure 8. Splitting tensile strength of 750 kg/m³ density LF with different weight fractions of CFF

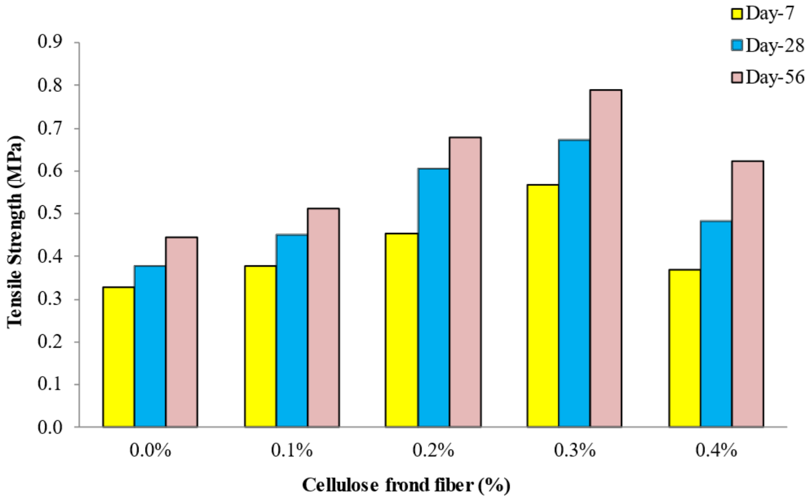

Figure 9. Splitting tensile strength of 1000 kg/m³ density LF with different weight fractions of CFF

CONCLUSION

This laboratory investigation explores the potential use of cellulose fibers (CFF) in lightweight materials to improve mechanical properties. A volume fraction of 0.3% of CFF was the optimum percentage in LF, which resulted in excellent compressive, bending, and splitting tensile strength. CFF helped to prevent the occurrence of microcracks in the plastic state of LF. In addition, CFF exhibits high elongation at break, which can lead to a better affinity between the cementitious matrix and the fibers. CFF reacts like an aggregate, making the microstructure denser, reducing the size of voids, and thus refining the arrangement of pores.

REFERENCES

[1] ASTM International. ASTM C293 / C293M-16: 2016. *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Center-Point Loading)*. West Conshohocken, PA: ASTM International.

[2] ASTM International. ASTM C496 / C496M-17: 2017. *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens.* West Conshohocken, PA: ASTM International.

[3] British Standard Institution. BS 12: 1996. *Specification for Portland cement.* British Standards Institute

[4] British Standard Institution. BS 12390-3: 2011. *Testing hardened concrete. Compressive strength of test specimens*. London, United Kingdom: British Standards Institute.

[5] British Standard Institution. BS 882: 1992. *Specification for aggregates from natural sources for concrete*. London, United Kingdom: British Standards Institute.

[6] Castillo-Lara, J. F., Flores-Johnson, E. A., Valadez-Gonzalez, A., Herrera-Franco, P. J., Carrillo, J. G., Gonzalez-Chi, P.I. & Li, Q.M. 2020. Mechanical Properties of Natural Fiber Reinforced Foamed Concrete. *Materials*, 13(14), 3060

[7] Elrahman, M. A, El Madawy, M. E., Chung, S. Y., Sikora, P. & Stephan, D. 2019. Preparation and characterization of ultra-lightweight foamed concrete incorporating lightweight aggregates. *Applied Sciences*, 9(7), 1-12.

[8] Fu, Y., Wang, X., Wang, L. & Li Y. 2020. Foam Concrete: A State-of-the-Art and State-of-the-art Practice Review. *Advances in Materials Science and Engineering*, 2020, Article ID 6153602.

[9] Hamad, A. J. 2014. Materials, production, properties and application of aerated lightweight concrete. *International Journal of Materials Science and Engineering*, 2(2), 152-157.

[10] Hanizam, A. & Ahmad, M. H. 2014. Durability properties of foamed concrete with fiber inclusion. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 8(3), 269-272

[11] Huang, Z., Zhang, T. & Wen, Z. 2015. Proportioning and characterization of Portland cement-based ultra-lightweight foam concretes. *Construction and Building Materials*, 79, 390-396.

[12] Ketty, B., Arsene, M. A. & Ouensanga, A. 2007. Study of banana and coconut fibers: Botanical composition, thermal degradation and textural observations. *Bioresource Technology*, 98(1), 58-68.

[13] Klyuev, S. V., Khezhev, T. A., Pukharenko, Y. V. & Klyuev, A. V. 2018. Fiber Concrete on the Basis of Composite Binder and Technogenic Raw Materials. *Materials Science Forum*, 931, 603-607.

[14] Lim, S. K., Tan, C. S., Lim, O. Y. & Lee, Y. L. 2013. Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. *Construction and Building Materials*, 46, 39-47.

[15] Mahzabin M. S., Hock, L. J., Hossain, M. S. & Kang, L. S. 2018. The influence of addition of treated kenaf fibre in the production and properties of fibre reinforced foamed composite. *Construction and Building Materials*, 178, 518-528.

[16] Mohammadhosseini, H., Awal, A. S. M. A. & Sam, A. R. M. 2016. Mechanical and thermal properties of prepacked aggregate concrete incorporating palm oil fuel ash. *Sadhana*, 41(10), 1235-1244.

[17] Momeen, M., Islam, U., Mo, K. H. & Alengaram, U. J. 2016. Durability properties of sustainable concrete containing high volume palm oil waste materials. *Journal of Cleaner Production*, 137, 167-177.

[18] Munir, A., Abdullah, Huzaim, Sofyan, Irfandi & Safwan. 2015. Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material. *Procedia Engineering*, 125, 739-746.

[19] Sari, K. A. M. & Sani, A. R. M. 2017. Applications of Foamed Lightweight Concrete. *MATEC Web of Conferences*, 97, 1-5.

[20] Savastano Jr, H., Warden, P. G. & Coutts, R.S.P. 2000. Brazilian waste fibres as reinforcement for cement-based composites. *Cement and Concrete Composites*, 22(5), 379-384.

[21] Serri, E., Othuman Mydin, M. A. & Suleiman. M. Z. 2014. Thermal properties of Oil Palm Shell lightweight concrete with different mix designs. *Jurnal Teknologi*, 70(1), 155-159.

[22] Zhu, W. H., Tobias, B, C., Coutts, R. S. P. & Langfors, G. 1994. Air-cured banana-fibre-reinforced cement composites. *Cement and Concrete Composites*, 16(1), 3-8.