SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Durability Properties of Lightweight Foamed Concrete Reinforced With 'Musa Acuminate' Fibre

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ARTICLE INFO

Article history:
Received 5 November 2022
Received in revised form 27 November 2022
Accepted 19 December 2022
Available online 10 January 2023

Keywords:
Foamed concrete; Musa acuminate fibre; Water absorption; Porosity; Shrinkage

ABSTRACT

The demand for lightweight building materials that are easy to work with, self-compacting, and environmentally friendly has been acknowledged by the construction industry globally. Given this demand, it has been discovered that a recent innovative material, lightweight foamed concrete (LFC), may be able to reduce the weight of ordinary concrete. Besides, utilizing LFC with the addition of natural fibres is seen as a great effort to assist sustainability. Corrosion of reinforcing steel, which affects the behaviour and longevity of concrete buildings, is one of the most significant challenges in the construction of reinforced LFC. Therefore, the focus of this work is on identifying the possible application of Musa Acuminate fibre (MAF) in LFC. The intention of this study is to ascertain the durability characteristics of LFC with MAF. The cast has a low density of 550 kg/m3. We'll employ several volume fractions of MAF that are 0.15%, 0.30%, 0.45%, and 0.60%. The ability to absorb water, porosity, drying shrinkage and ultrasonic pulse velocity are the four criteria that will be evaluated. For the purpose of creating the necessary density of LFC, the protein-based foaming agent Noraite PA-1 was used. A constant water-to-cement ratio of 0.45 and a constant cement-to-sand ratio of 1.5 were used to get comparable results. The findings showed that for all of the durability attributes taken into account in this research, an increase of 0.45% MAF produced the best results. This resulted from the MAF and LFC cementitious composite's better bonding performance. Additionally, the fibres served as an anti-micro crack, preventing LFC cracks.

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https://doi.org/10.37934/araset.29.2.145158

1. Introduction

Globally, there has been a lot of research on green concrete due to the concern for environmentally friendly construction. There has been an increase in the study using resources sparingly and sustainably throughout the life cycle. Concrete mix design, mix material procurement, construction method, construction technology, and concrete structure maintenance have all received special attention [1]. Thus, it may be inferred that the key role that industrial players play in ensuring sustainable development in society. The majority of building materials are made from non-sustainable resources that need a lot of energy to generate and pose a threat to the environment. As a result, the manufacture of concrete can use lightweight foamed concrete (LFC), which helps to address these issues [2]. Using LFC in construction has many benefits, including providing excellent thermal insulation, superior fire resistance, and lightweight construction that uses fewer ingredients in concrete, such as cement, fine aggregates, stable foam, and water. In LFC, these materials are typical. In order to increase the LFC's strength, another admixture can be used.

Due to the absence of aggregates, LFC becomes lighter and is also noted for its good workability, low cement content, and minimal use of aggregate. Additionally, it is combustible, simple to make, and eco-friendly. However, a longer period is required to mix it to guarantee that the components are properly combined to produce the desired density of LFC. The strength and longevity of LFC are increased by the addition of fibre [3]. Meanwhile, it has been demonstrated that concrete's durability is less affected by early age when the volumetric content of short fibres is minimal. The increased use of LFC as concrete blocks, floor screed, and roof insulation is made possible by the growth in the significance of surfactants like foaming agents and foam producers.

The creation of stable LFC will be impacted by the many choices of foaming agents, foam production techniques, LFC manufacturing techniques, kind of mixers, and time spent mixing LFC. Therefore, the LFC's combination can be changed or replaced with other materials to generate LFC that is stronger and more durable. For instance, silica fume and fly ash are used in place of sand in LFC in the current research [4]. In other words, the composition of materials, such as material selection, mixture design, and foam preparation, needs to be regulated to improve its potential as a structural element. Additionally, LFC's weight was decreased by the absence of coarse particles [5]. LFC has been found to function as a structural, semi-structural, and non-structural element in addition to a thermal insulator [6].

The effectiveness of fibres in mixtures in terms of their durability properties has been proved by numerous studies on the issue. It can be divided into natural fibres produced by plants, animals, and geological processes, as well as synthetic fibres created by humans [7]. The most delicate fibres are a great essence since they increase the ductility, strength, and shrinkage of LFC. It is critical to realize that making synthetic fibres from sawdust, straw, or fibreglass consumes a significant amount of energy [8]. Even though the materials are inexpensive and simple to utilize, they are not naturally sustainable [9]. These materials have a flaw in that they tend to absorb water in moist environments and lose their insulating qualities [10]. Additionally, the LFC has low tensile strength, is readily broken, and has a shrinking issue in low density [11,12]. Therefore, the use of *musa acuminate* fibre (MAF) could enhance the LFC's mechanical attributes.

Due to the LFC's low tension compared to the capacity in compression, the MAF may also improve the performance of bending and tensile cracking [13,14]. Cracks are a serious problem that will impact the concrete's quality, serviceability, and aesthetics in particular [15]. Additionally, the higher percentage of fibre is what contributes to the segregation and roughness of the concrete and mortar [16,17]. Determining the quantity of fibres, cement, sand, water, and foaming agent in the mixture is, therefore, crucial [18]. One of the main reasons why synthetic fibre is garnering so much attention is because natural fibres are seen as sustainable resources [19,20]. Natural fibres provide several benefits over synthetic fibres, such as being biodegradable, having a low density, and is challenging to melt when heated [21]. When creating and manufacturing construction materials, natural fibres can be employed to reinforce cementitious materials. Natural fibres include bamboo, bananas, coir, cane, and henequen [22].

High-strength natural fibre MAF is easily used in blended fabrics and textiles, as well as with cotton or other synthetic fibres. High-quality paper, packaging materials for agricultural goods, car towing ropes, wet drilling cords, etc. all use MAF. MAF, however, is frequently discarded as agricultural waste [23]. Several plans that emphasized lower material costs have been suggested despite the urgent requirement for Malaysian residents to live in affordable housing and produce green concrete. Therefore, it is advised to use agricultural waste as a full replacement for building materials. The durability characteristics of LFC could be enhanced by the MAF [24]. These days, there are a lot of published papers on MAF uses and ongoing research in concrete base materials. An effort is being made to find new and improved fibres that could improve the LFC durability performance. It's crucial to realize that MAF can make LFC more durable. Despite this, several concerns still need to be resolved, such as the MAF's capabilities and level of improvement. The purpose of this research is to determine whether MAF could be used to increase the durability of LFC.

2. Materials and Mix Design

There were 5 LFC mixes in total, each with a density of 550 kg/m3. In this laboratory evaluation, the percentages of volume fraction of MAF fibre used were 0.00% (control), 0.15%, 0.30%, 0.45%, and 0.60%. Because the researcher discovered during the pilot study that the addition of MAF volume fraction of more than 0.6% led to fibre aggregation and non-uniform dispersion during mixing, the range of fibre volume fraction between 0.15% and 0.60% was chosen in this investigation. The water-cement (W: C) ratio was held constant at 0.45 for all the mixtures, and the sand-cement (C:S) ratio was 1:1.5. Table 1 displays the study's mix proportions.

Table 1
LFC mix design

Sample	Density (kg/m^3)	Ratio C:W:S	MAF	Cement	Sand	Water
Control	550	1:1.5:0.45	-	16.91	25.36	7.61
0.15% MAF	550	1:1.5:0.45	0.074	16.91	25.36	7.61
0.30% MAF	550	1:1.5:0.45	0.149	16.91	25.36	7.61
0.45% MAF	550	1:1.5:0.45	0.224	16.91	25.36	7.61
0.60% MAF	550	1:1.5:0.45	0.299	16.91	25.36	7.61

Ordinary Portland Cement which met the BS12 Standard and was provided by YTL Castle Cement Marketing Sdn. Bhd. was used for this experimental endeavor. All the cement was in good shape and was kept under cover. Next, natural fine sand that was purchased from a nearby distributor was used as the final fine aggregate. The fine filler (sand) with a maximum width of 2 mm, a throughput of 60% to 90%, and a filter of 600 microns as utilized. Sand's suitability had to adhere to BS822. Noraite PA-1, a protein-based foaming agent, was the one that was employed. Due to its stability and smaller bubbles, which produce a stronger bubble bonding structure as compared to a synthetic-based protein, this Noraite PA-1 was chosen as the foaming agent. Next, the tap water must be crystal-clear and uncontaminated. Water was necessary for the curing process, mixing the LFC, and preparing the mortar. Based on earlier research, the water-cement ratio used in this study was 0.45, which can produce satisfactory workability. Finally, MAF, which had just been processed, had been newly gathered from an industrial unit, was the fibre used. The MAF had a grease layer on top of it that would encourage the growth of fungi and deterioration. It was necessary to wash the MAF several times till the grease was removed. The MAF was set out to dry in the sun.

The chemical composition, physical characteristics, and mechanical properties of MAF are shown, respectively, in Tables 2, Table 3, and Table 4. MAF had a high percentage of cellulose, which may be quite helpful when used in a composite action with a cement matrix. Figure 1 shows the cross-section of MAF. The experimental evidence obtained in this work confirms that natural fibres with a high cellulose content typically exhibit a low deformation capacity and superior young's modulus. Additionally, it was noted that a rise in the cellulose content of plant fibres generally results in an increase in tensile strength and young's modulus. Figure 2 reveals the FTIR spectrum result of MAF.

Table 2
MAF chemical composition

Composition	%, dry weight
Hemicellulose (%)	28.6
Cellulose (%)	41.2
Lignin (%)	21.1
Moisture (%)	2.6
Ash (%)	2.3
Extractives (%)	3.8

Table 3
MAF physical properties

Component	Properties
Length	20mm
Diameter	269 um
Width of lumen	15.99 um
Density	0.81 g/cm^3
Runkel ratio	0.259
Angle of fibril (º)	42

Table 4
MAF mechanical properties

Component	Properties
Tensile strength (MPa)	150.4
Young’s modulus (MPa)	14894
Elongation at break (%)	11.53

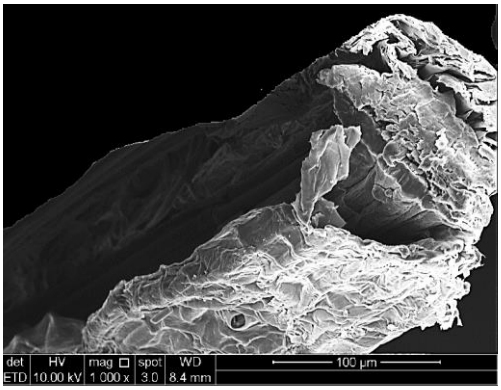


Fig. 1. Cross-section of MAF

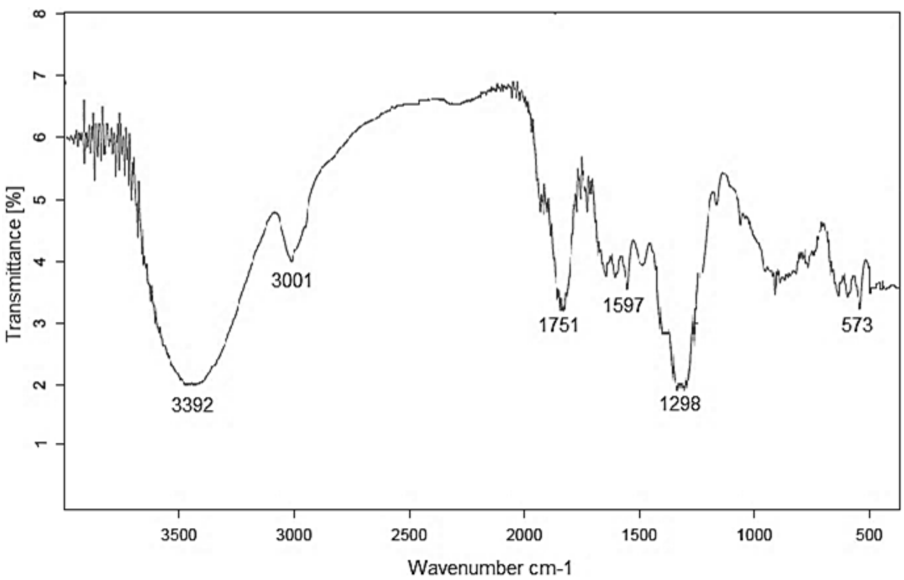


Fig. 2. FTIR spectrum for MAF

3. Experimental Setup

3.1 Water Absorption Test

The water absorption test measures the water absorption rate (sorptivity) of both the exterior and interior surfaces of concrete. The test measures the increase in mass of concrete samples due to water absorption as a function of time when only one side of the specimen is exposed to water. With reference to BS1881-122, the water absorption test was carried out on a cylinder that measured 75mm (diameter) and 100mm (height). A day before the curing procedure, the cylinder specimen was removed, cleaned, and weighed to measure the dry weight. The item was then placed in an oven set at 105 °C for 72 hours to ensure that it was completely dry before the test. Below is a calculation of water absorption:

$$Wa = \frac{Wsat - Wwet}{Wdry} \, x \, 100\% \tag{1}$$

where,
W_a = Absorption of water
W_{sat} = Foamed concrete's saturated surface dry weight
W_{dry} = Specimen's weight after oven drying
W_{wet} = Sample weight in water

3.2 Porosity Test

Utilizing the Vacuum Saturation Apparatus, the porosity value was calculated. For three days, the dried samples were kept in a desiccator under a vacuum. Water that had been de-aired and distilled was poured into the desiccator at that time. To determine the oven-dry mass, the specimens were kept in a vented oven at 105 °C for three days. The specimens were then taken out of the oven and allowed to cool at room temperature. Finding the specimens' oven-dray mas and getting them ready for vacuum saturation are the goals of weight measurement. The vacuum will pump and last for three days while the vacuum line connector is connected to a pressure gauge. The following calculation can be used to calculate the porosity of foamed concrete:

$$Pr = \frac{Wsat - Wdry}{Wsat - Wwet} x\ 100\% \quad (2)$$

where,
P_r = Porosity
W_{sat} = Foamed concrete's saturated surface dry weight
W_{dry} = Specimen's weight after oven drying
W_{wet} = Sample weight in water

3.3 Drying Shrinkage

The drying shrinkage is the difference between the original wet and dry measurements of the rectangular moulded sample, expressed as a percentage of dry length. ASTM C878 was followed in performing this test. The prism utilised was 75mm long and had a total estimated length of 290mm, including the rod and cap nuts. To get the average result for each test, a minimum of 3 specimens were collected. A length comparator with a 250m invar bar that can correct the measurement to 0.001mm was used to take the initial length measurement. For each specimen, the comparator's length was checked against a standard invar. The following equation is used to calculate the drying shrinkage.:

$$L = \frac{Lx - Li}{G} x\ 100 \quad (3)$$

where,
L = Length change
L_x = Variation between the comparator reading at age
L_i = Initial reading
G = Gauge length

3.4 Ultrasonic Pulse Velocity Test

By determining the transmission speed of a transferred longitudinal ultrasonic pulse over the cross-sectional area, the Ultrasonic Pulse Velocity (UPV) test was executed. Mortar prisms were measured to be 100 mm x 100 mm x 500 mm in size. The transmission of an ultrasonic pulse was examined using an electro-acoustical transducer. A second transducer holds it in place with an electrical signal after the pulse travels a specified distance through the specimen. The transmitted time and velocity were then displayed to the magnetic transducer. The standard processes were carried out in accordance with the BS EN 12504-4 standard. For all mix designs, a mortar prism of 100 mm by 100 mm by 500 mm was built, and it was checked on days 7, 28, 60, and 180 of the curing process. Readings were taken, and the UPV result’s average velocity was calculated.

4. Results and Discussion
4.1 Water Absorption

To ascertain the water absorption in LFC, a water absorption test is carried out. Figure 3 depicts the water absorption with the addition of MAF at various MAF percentages. The graph shows that the MAF in the LFC grew while the water absorption decreased. The MAF inclusion in LFC, 0.6% by mix, results in the lowest water absorption, which is 17.5%, as opposed to the inclusion of 0.15% MAF by mix, which results in 22.2% water absorption, which is the cause of the declining trend. The second-lowest level of water absorption, at 18.1%, had 0.45% MAF in LFC. This was followed by 19.9% water absorption, which had 0.30% MAF.

Because of the LFC's low density and higher foam content, which results in more air space, this result may indicate that the LFC, which has a density of 550 kg/m^3, has a high capacity for water absorption. With reference to the SEM micrograph result in Figure 4, the control LFC specimen (with no addition of MAF) has large interconnected pores. Compared to Figure 5, the void sizes were reduced with the presence of MAF and the MAF plays an important role to fill the cavity thus reducing the water absorption capacity of LFC. The bigger pores in the lower density of LFC, 550 kg/m^3, led to the weak matrix corporation that can impair LFC quality [25]. Furthermore, the pores in the LFC that are close to one another will join to form larger pores. Brittleness and the emergence of microstructure failure, which results in LFC, will be to blame for this [26, 27]. LFC will slow down the rate of water absorption.

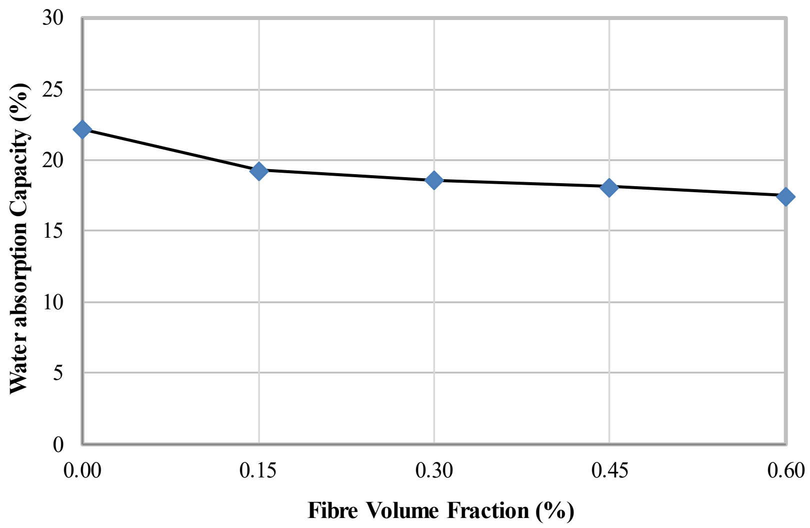


Fig. 3. Water absorption of 550kg/m^3 with various MAF volume fractions

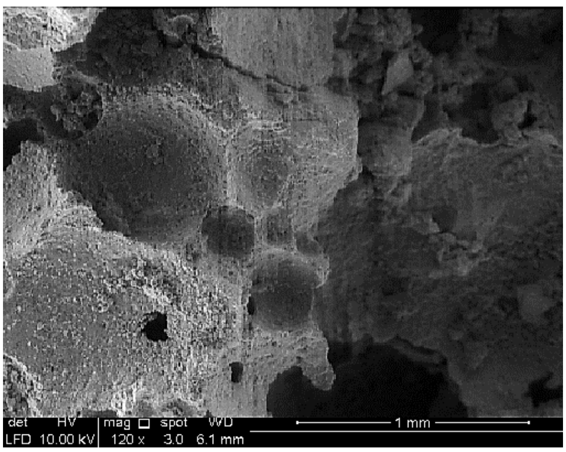


Fig. 4. Morphology of control LFC

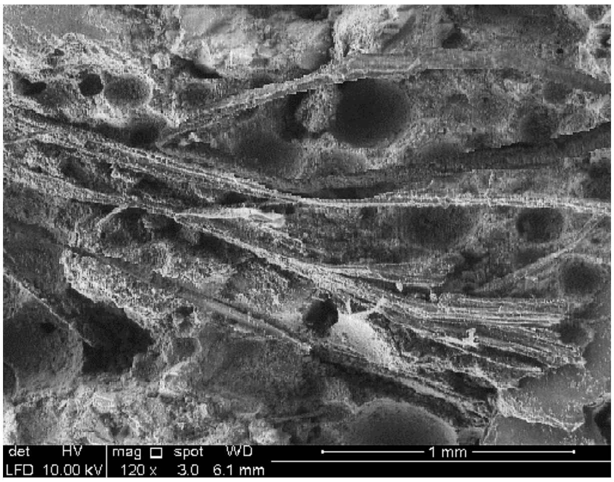


Fig. 5. Morphology of LFC with the inclusion of 0.3% of MAF

4.2 Porosity

A porosity test can be used to calculate the size of the voids in a concrete sample. Permeability is the measure of how quickly moisture permeates through concrete when there is a pressure gradient. Concrete has gaps that allow for the passage of moisture. A tiny pore in the concrete can slow the flow of moisture. The mechanical properties of LFC will be impacted by the porosity and pore structure. As a result, decreasing the porosity percentage will increase the strength of LFC. The proportion of LFC porosity is depicted in Figure 6 along with various MAF ratios. Along with the rise in MAF in the LFC, the percentage of porosity is on the decline. The findings indicate that the LFC with the lowest percentage of porosity, 62.3%, contained 0.6% of MAF, while the LFC with the highest percentage of porosity, 67.1%, contained 0.15% of MAF.

The graph demonstrates that 0.45% and 0.30% of MAF in LFC result in, respectively, 66.4% and 63.5% of porosity. The addition of MAF to the LFC affects the percentage of porosity. LFC's low density of 550 kg/m3 will result in a more porous structure. In order to get a greater porosity value, a lower density of LFC has a high proportion of foam. Therefore, a higher porosity value will result in a lower compressive strength for LFC. This is brought on by the weakening of the surface area between the pores and matrix. The enormous volume of foam also prevents items with a lower LFC density from adhering [28]. However, MAF immediately enhances the matrix in the LFC and boosts compressive strength [29].

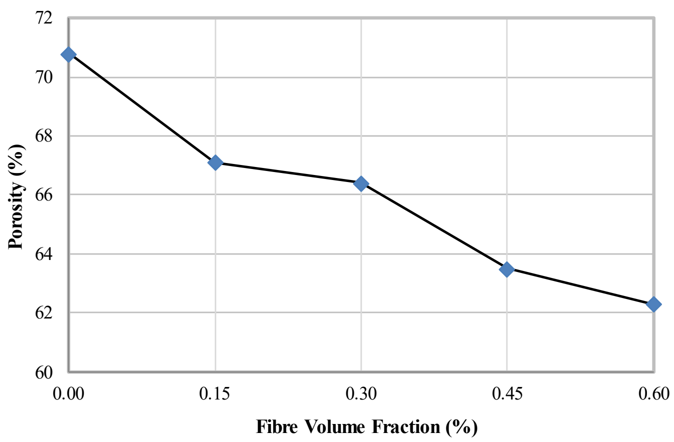
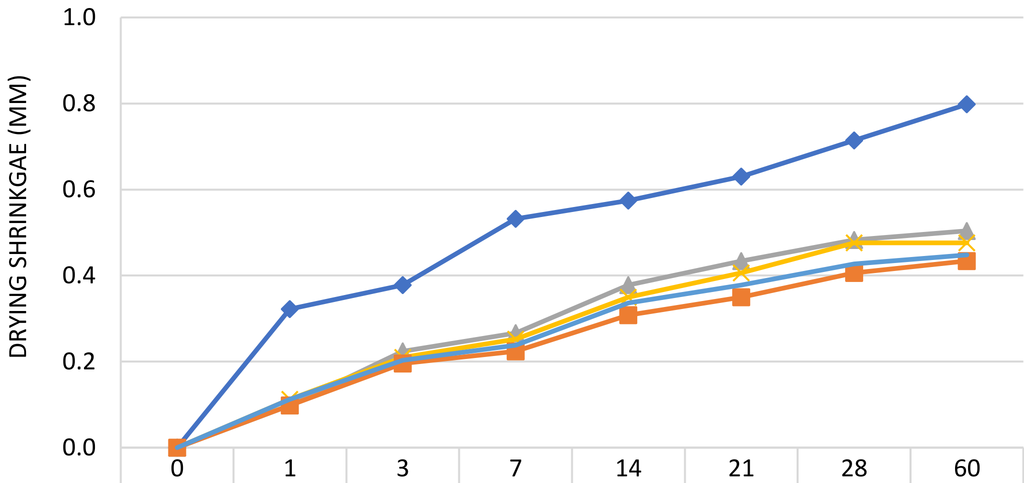


Fig. 6. Porosity of LFC with various MAF volume fractions

4.3 Drying Shrinkage

The contraction of the concrete mixture as a result of water loss is known as drying shrinkage. The drying shrinkage tests allowed researchers to estimate concrete's expansion. When under load, this shrinkage may increase tensile stress and result in cracking. Therefore, the purpose of this experimental test is to clarify how MAF can withstand changes in concrete volume. The specimens are all dramatically enlarged from day 1 until day 28 and begin continuous reading on day 28 until day 60, according to Figure 7. In comparison to specimens with MAF in LFC and a density of 550 kg/m3, the control specimens display the highest reading.

Additionally, the LFC with the lowest drying shrinkage contained 0.45% MAF, followed by 0.60%. 0.30% and 0.15%. The shrinkage of the concrete is improved by LFC when MAF is added. The increase in foam content in the concrete is what had an impact on shrinkage behaviour. This is due to the fact that using more foam will result in less cement paste usage, as stated by [30]. Additionally, the addition of MAF where aggregates are lacking results in a reduction in drying shrinkage, and MAF also helps to strengthen the cement matrix. Additionally, it aids with reducing the LFC's cracks [31]. Therefore, it may be argued that adding MAF to the LFC will lessen drying shrinkage.



	0	1	3	7	14	21	28	60
control	0	0.322	0.378	0.532	0.574	0.63	0.714	0.798
0.15%	0	0.098	0.224	0.266	0.378	0.434	0.483	0.504
0.30%	0	0.112	0.21	0.252	0.35	0.406	0.476	0.476
0.45%	0	0.098	0.196	0.224	0.308	0.35	0.406	0.434
0.60%	0	0.112	0.203	0.238	0.336	0.378	0.427	0.448

Fig. 7. Drying shrinkage of 550kg/m^3 density with various MAF volume fractions

4.4 Ultrasonic Pulse Velocity (UPV)

In this study, the UPV test's purpose is to evaluate the concrete's strength. Additionally, it can identify any cavities, honeycombing, or other discontinuities in the LFC. Where it identifies the heterogeneous zones in the LFC, the mechanical strength has an impact on the velocity of ultrasonic energy. Higher velocity results can be attained when the uniformity and density of the LFC are good. The outcomes of the UPV test on the 550kg/m^3 LFC specimens are shown in Figure 8. With the rise in MAF in the LFC, the UPV trend is rising. In contrast to the control mixes, which have the lowest readings of UPV (1387 m/s), the inclusion of 0.6% of MAF in the LFC produced the highest reading of UPV, which is 1559 m/s.

In addition to MAF, UPV results were obtained for 0.15%, 0.30%, and 0.45% in the LFC, where they have corresponding speeds of 1442 m/s, 1477 m/s, and 1508 m/s. As previously indicated, the existence of voids and variations in LFC affect the outcomes of UPV. As a result, when the LFC has a higher density, the pulse will move with a higher velocity. In addition, if it notices any indication of LFC malformation, it will slow down time travel [32]. Therefore, it can be said that the MAF's addition caused the UPV value readings to become more meaningful.

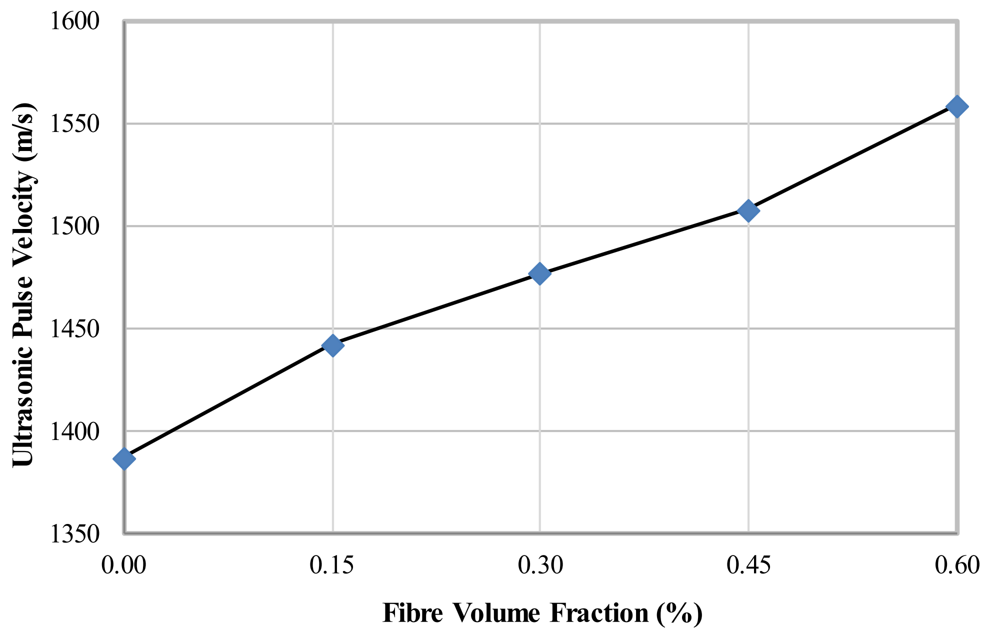


Fig. 8. Ultrasonic Pulse Velocity of 550kg/m^3 LFC with various MAF volume fractions

4.5 Relationship Between Water Absorption and Porosity

The relationship between water absorption and porosity for LFC with a density of 550 kg/m3 is shown in Figure 9 below. Various MAF concentrations were mixed in with the LFC before being applied. The graph below demonstrates the spread in results for both porosity and water absorption. The linear line represents the best trend relationship between water absorption and porosity, and the R2 value, which is close to 1, illustrates the association between the two results. Jawaid and Abdul Khalil [33] assert that as porosity increases, so does water absorption. The graph's linear line's outcome demonstrated that water absorption is directly inversely proportional to porosity. Lightweight LFC density is less durable and absorbs more water. The pore structure of LFC cement paste influences both water absorption and porosity [34].

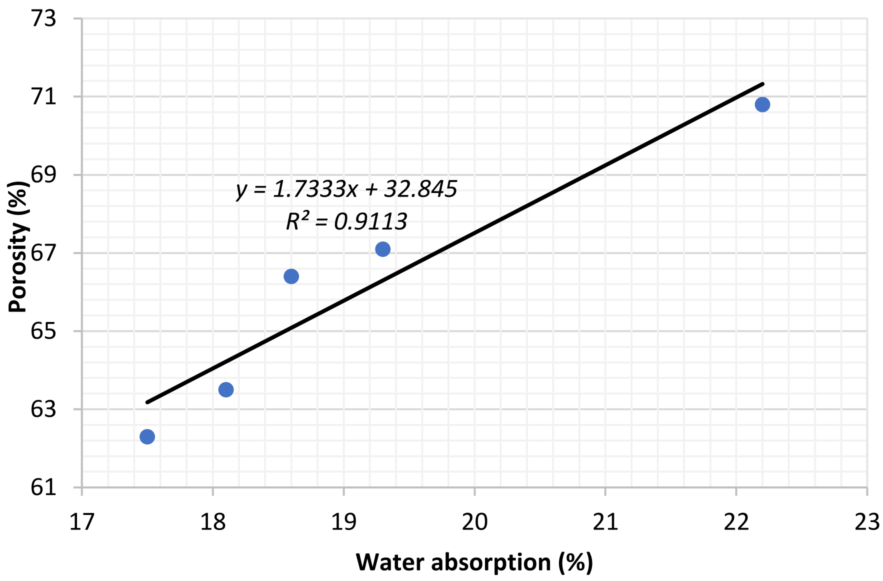


Fig. 9. Relationship between water absorption and porosity

4.6 Relationship Between Porosity and Ultrasonic Pulse Velocity

The relationship between LFC 550 kg/m^3 and different MAF percentages is seen in Fig. 10. The outcome of UPV and porosity, which have scattered in data, is depicted in the image below. The relationship between UPV and porosity is represented by a linear line, where the R2 value is displayed in the figure. The close association between UPV and porosity can be used to explain the value of R2, which is close to one. The graph shows that the UPV decreases in tandem with the porosity reduction. The difference in UPV between the dry and saturated states is caused by the material's pores changing shape because of moisture absorption. The graph's outcome demonstrated that the LFC's UPV value decreased as porosity increased. This indicates that the improvement in UPV and porosity value was caused by the addition of MAF. Lower trip time is associated with higher LFC quality and fewer abnormalities [35].

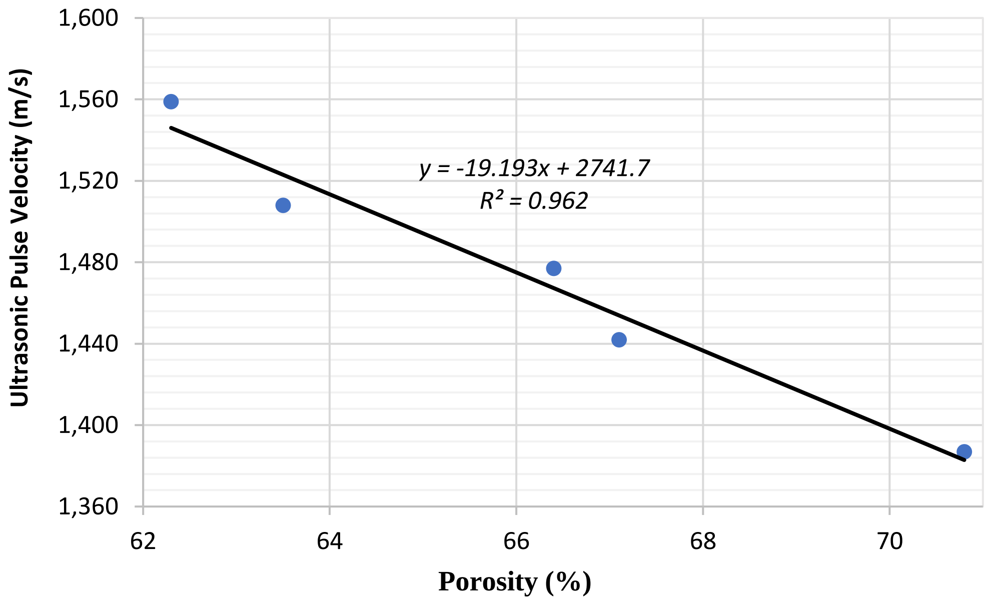


Fig. 10. Relationship between porosity and ultrasonic pulse velocity

5. Conclusion

In this experiment, different densities of LFC were mixed with various ratios of *musa acuminate* fibre (MAF) to test the durability properties of LFC. Five different MAF addition percentages of 0.00%, 0.15%, 0.30%, 0.45%, and 0.60% were used to generate and evaluate a 550 kg/m^3 density. According to the testing findings, the inclusion of a 0.45% volume fraction of MAF produced the greatest results in terms of durability qualities (water absorption, porosity, drying shrinkage, and ultrasonic pulse velocity). The fibres and cementitious matrix reached their maximum compaction at 0.45% volume fraction of MAF, which produced good mix regularity. Beyond the optimum degree of MAF addition, agglomeration and uneven fibre dispersal were seen, which decreased all of the study's durability properties.

Acknowledgement
The authors would like to acknowledge the Ministry of Higher Education, Malaysia for the financial support under the Fundamental Research Grant Scheme with project code: FRGS/1/2022/TK01/USM/02/3

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