

# Investigating the Effect of Sisal Fibre Content on Durability Properties of Lightweight Foamed Concrete

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## ABSTRACT

Lightweight foamed concrete is greatly permeable, and its durability performance reduce with rising in the number of voids. In turn to improve its durability properties, the solid matrix of lightweight foamed concrete can be adjusted by incorporating several plant-based fibres. The effect of sisal fibre in lightweight foamed concrete was not explored before in the current body of knowledge. Therefore, there is some uncertainty considering the mechanism by which and the extent to which the sisal fibre may impact lightweight foamed concrete durability properties. Thus, this laboratory study concentrates on distinguishing the potential employment of sisal fibre into lightweight foamed concrete. This investigation aims to establish the durability performance of lightweight foamed concrete with the presence of sisal fibre. Densities of 800 and 1600 kg/m<sup>3</sup> were made and assessed. Different weight fractions of sisal fibre of 0.2%, 0.4%, 0.6% and 0.8% were utilized. There were four durability performance of lightweight foamed concrete were evaluated such as shrinkage, ultrasonic pulse velocity (UPV), porosity and water absorption capacity. The experimental results had indicated that the addition of 0.6% of sisal fibre gave the optimum results for the durability properties. At 0.6% weight fraction of sisal fibre, the fibres reached maximum compaction in the cement matrix, which stemmed in exceptional mix regularity. Further than 0.6% inclusion of sisal fibre, accumulation and non-regularity scattering of fibres was detected, which led to reduction in entire parameters assessed.

**Keywords:** lightweight foamed concrete; sisal fibre; porosity; shrinkage; water absorption

## INTRODUCTION

These days, concrete is the most widely utilized building material worldwide as generally it can be said that it is fragile in nature. It is recognized that concrete elements are reinforced with essential reinforcements to withstand compressive stresses in contrast to tensile strains [1]. Strengthening bars are employed to prevail over the deficiency of concrete ductileness. Nevertheless, inclusion of rebars significantly enhances the concrete load carrying capacity although the expansion of micro-cracks should be managed to produce concrete with reliable yielding attributes. Numerous fibres are used in concrete to control the plastic shrinkage [2]. It is assigned corresponding to weight fraction which commonly between 0.2 to 5.5%. Fibres are randomly dispersed and sporadic in the cementitious composite. The

fibre reinforced concrete can be classified into four types which are glass, steel, natural and synthetic fibres. Fibre-reinforced concrete comprises of mortar or concrete with asymmetrical, diverse, and homogeneously distributed fibres. Uninterrupted interlinks and bars are not considered to be distinctive fibres [3].

Lightweight foamed concrete is a lightweight material comprising of Portland cement with a uniform cavity generated by creating air in the form of stable bubbles. With an accurate mechanism in the production of stable foam and appropriate techniques of fabrication, a broad scale of lightweight foamed concrete densities starting from 500 to 1700 kg/m<sup>3</sup> can be manufactured [4]. Global interest of eco-friendly building materials has driven a lot of research on green concrete universally. Recognition has been given to areas such as concrete mix design, mix material sourcing,

construction method, construction technology, and concrete structure maintenance. Consequently, achieving sustainable development in the construction industry depends on the important role played by the industry players. Commonly, most of the construction materials are produced from non-sustainable products that need a high amount of energy which cause a global crisis. Therefore, plant fibre can be utilized in lightweight foamed concrete production, contributing to resolving these complexities [5]. There are numerous advantages when using lightweight foamed concrete in construction, such as providing excellent thermal insulation, outstanding fire resistance performance, light in weight and reduce the consumption of few basic materials in concrete for instance cement and fine fillers [6].

Integration of plant fibres into lightweight foamed concrete improves its mechanical, thermal and durability properties. It has been shown that a low volumetric of the short plant fibres decrease the effect of early age on the durability of concrete. It is important to distinguish the number of fibres, cement, sand, water, and foaming agent in the mixture. Plant fibres have numerous benefits in excess of the synthetic fibres such as they are biodegradable, low in density, and are difficult to melt when heat up. Plant fibres can be utilized to strengthen cementitious materials. There were some attempts by various researchers to ascertain the durability and engineering properties of lightweight foamed concrete reinforced by plant and synthetic fibres. Nensok Hassan et al. [7] embarked on research efforts using banana fibre in lightweight foamed concrete. They found that banana fibre acted well in the cementitious composite to enhance the attachment between cement matrix of lightweight foamed concrete and the fibre improved the durability and engineering properties of the composite. Comparable research attempts were accomplished with the inclusion of steel fibre. The research discovered that the lightweight foamed concrete composites' durability properties reduce with a rise in the steel weight fraction compared to the control specimen. These results revealed that while banana plant fibre improves lightweight foamed concrete mechanical and durability properties, steel fibre reduces the durability performance. Raj et al. [8] appraised the engineering performance of foamed concrete reinforced with polyvinyl alcohol fibre and coconut fibre. They found that lightweight foamed concrete strengthened

with coconut fibre behaves better than that intensified with polyvinyl alcohol fibre.

From the above review, the influence of sisal fibre addition in lightweight foamed concrete for durability properties improvement is not well explored and recognized. Consequently, this research concentrates on establishing the lightweight foamed concrete durability performance strengthened with sisal fibre. Densities of 800 and 1600 kg/m<sup>3</sup> were made with different weight fractions of sisal fibre and the composites' durability properties were investigated.

## MATERIALS AND METHODS

There was a total of ten lightweight foamed concrete mixes of 800 kg/m<sup>3</sup> and 1600 kg/m<sup>3</sup> densities were manufactured. The weight fraction of sisal fibre utilized in this study were 0.2%, 0.4%, 0.6% and 0.8%. A control lightweight foamed concrete specimen without any addition of sisal fibre was also prepared for comparison reasons. The range of sisal fibre weight fraction between 0.2% to 0.8% had opted in this research was because, during the preliminary investigation, the researcher had found that the inclusion of sisal fibre weight fraction beyond 0.8% led to the accumulation of sisal fibre during lightweight foamed concrete mixing process. The cement to sand proportion used was 1:2 and the water to cement proportion applied was 0.5. Table 1 illustrates the mix proportions. Ordinary Portland cement was employed following BS12 specification. Then, the filler employed was fine sand with a maximum width of 2mm and a 600-micron sieve, and a passage of 61% to 91% in accordance with BS822. Finally, the fibre utilized was sisal fibre with different weight fractions of 0.2%, 0.4%, 0.6% and 0.8%.

Tables 2, 3 and 4 demonstrate the chemical arrangement, compositional ranges, and mechanical and physical properties of sisal fibre correspondingly. Sisal fibre poses high cellulose content as per shown in Table 3 which may assist significantly when in composite action with lightweight foamed concrete cementitious matrix.

## EXPERIMENTAL SETUP

There were four durability property tests were conducted including drying shrinkage, porosity, water absorption capacity and ultrasonic pulse

**Table 1.** Mix design of lightweight foamed concrete

Specimen	Dry density (kg/m <sup>3</sup> )	Proportion (c:s:w)	Fine sand (kg)	Portland cement (kg)	Water (kg)	Sisal fibre (kg)
Control - 800	800	1:2:0.5	25.49	12.75	6.37	–
0.2% SF-800	800	1:2:0.5	25.49	12.75	6.37	0.09
0.4% SF-800	800	1:2:0.5	25.49	12.75	6.37	0.18
0.6% SF-800	800	1:2:0.5	25.49	12.75	6.37	0.27
0.8% SF-800	800	1:2:0.5	25.49	12.75	6.37	0.36
Control -1600	1600	1:2:0.5	49.84	24.92	12.46	–
0.2% SF-1600	1600	1:2:0.5	49.84	24.92	12.46	0.17
0.4% SF-1600	1600	1:2:0.5	49.84	24.92	12.46	0.34
0.6% SF-1600	1600	1:2:0.5	49.84	24.92	12.46	0.51
0.8% SF-1600	1600	1:2:0.5	49.84	24.92	12.46	0.68

**Table 2.** Chemical composition of sisal fibre

Element (wt%)	I	II	III	IV
C	6.21	7.19	8.32	13.99
O	17.22	15.88	10.05	17.64
Mg	0.04	a	a	a
Si	0.06	a	a	a
Ca	7.82	6.52	a	a

a – not detected.

**Table 3.** Compositional ranges of sisal fibre

Composition	%, dry weight
Cellulose (%)	56.4
Hemicellulose (%)	15.1
Lignin (%)	12.1
Pectin (%)	4.6
Water Soluble (%)	0.3
Wax (%)	1.7
Moisture (%)	9.8

**Table 4.** Physical and mechanical properties of sisal fibre

Component	Properties
Tensile strength (MPa)	297
Modulus of elasticity (MPa)	17500
Fracture strain (%)	2.88
Fibre length	17–19 mm
Density	1.31 g/cm <sup>3</sup>
Width of lumen	13.76 $\mu$ m
Diameter of fibre	376 $\mu$ m

velocity tests. Water absorption test was accomplished in line with BS1881-122 on 75×100 mm cylinder. The cylinder specimens were separated a day prior to the curing process, and the specimens were cleaned and weighed to establish the dry weight. Following this, the specimens were left in an electric oven at 100°C for 3 days to make sure that the specimens were fully dry. Figure 1 displays the water absorption test. Next, the porosity was determined via vacuum saturation device. The dried specimens were placed under a vacuum in a desiccator for three days. The samples were placed in a ventilated oven set to 100°C for three days to identify oven-dry mass. After that, the samples were taken from the oven and left at room temperature. The objective of determining the specimens' weight is to determine their oven-dry mass and, at the same time to prepare them for vacuum

saturation. Meanwhile, the vacuum line connector connects with a pressure gage, and the vacuum will pump and continued for three days. Figure 2 demonstrates the setup for porosity test. For the UPV test, a prism sample of 100×100×500 mm size was utilized in accordance with BS12504-4. Figure 3 shows the setup for UPV test. Finally, the shrinkage test was commenced in line with ASTM C878. A 75 mm with length 250 mm prism was used with an estimated overall length of 290 mm, including the rod and cap nuts as shown in Figure 4. For each test, a minimum of 3 specimens was taken to obtain the average result. The initial length measurement was taken with a length comparator equipped with a 250 m invar bar which capable of adjusting the measurement up to 0.001 mm. The comparator's length was adjusted against a reference invar for each specimen.



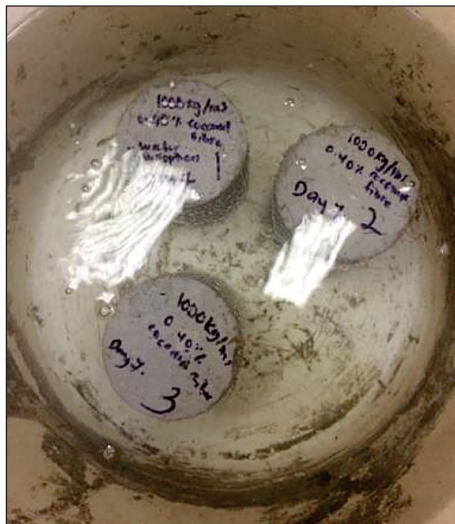


Fig. 1. Water absorption test



Fig. 2. Porosity test



Fig. 3. UPV test



Fig. 4. Shrinkage test

## RESULTS AND DISCUSSION

### Water absorption

Figure 5 reveals the water absorption results for 800 and 1600 kg/m<sup>3</sup> densities. For both densities, the water absorption capacity decreased as the weight fraction of sisal fibre in lightweight foamed concrete raised. The decreasing trend is due to the inclusion of sisal fibre, in which 0.8% weight fraction sisal fibre addition gave the least water absorption, which is 16.0% and 7.9% for 800 and 1600 kg/m<sup>3</sup>, compared to the presence of 0.2% of sisal fibre resulting in 22.4% and 11.3% water absorption value for 800 and 1600 kg/m<sup>3</sup> correspondingly. Meanwhile, the second lowest of water absorption is 19.6% (800 kg/m<sup>3</sup>) and

8.5% (1600 kg/m<sup>3</sup>) which contained 0.6% of sisal fibre in lightweight foamed concrete, followed with 0.4% of sisal fibre, which resulted in 18.6% water absorption value 20.7% and 9.1% for 800 and 1600 kg/m<sup>3</sup> correspondingly. As discovered, the lower density of LFC (800 kg/m<sup>3</sup>) has larger pores, which led to weak matrix corporation that can disrupt the quality of lightweight foamed concrete. Additionally, the pores in lightweight foamed concrete near each other will combine and produce large pores. This will be caused by brittleness and the development of microstructure failure which leads to enhancement of water absorption. Greater content of plant fibre like sisal managed to block water from probing due to tiny void diameters [9]. The dampness of sisal fibre was lost, and it dwindled onto their dimensions

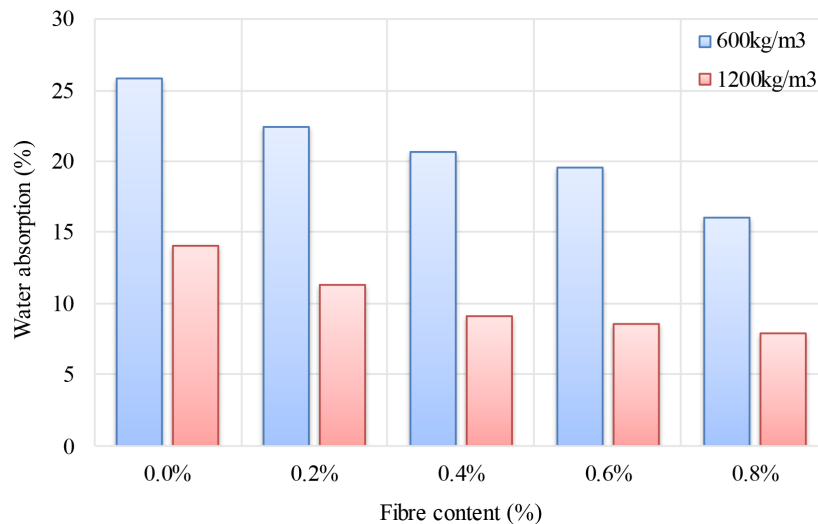


Fig. 5. Water absorption of foamed concrete with different sisal fibre weight fraction

due to drying process in the cementitious composite. Furthermore, the calcium silicate hydrate gel formation in matrix with higher percentage of fibre condensed the void size, which caused in reduced absorption of water [10].

### Porosity

Figure 6 demonstrates the recorded porosity of lightweight foamed concrete with various weight fractions of sisal fibre. The trend of porosity is declining along with the increase of sisal fibre weight fraction in lightweight foamed concrete. The results show that the lowest percentage of porosity is 55.8% and 11.8% for 800 and 1600 kg/m³ individually which contained 0.8% weight fraction of sisal fibre in lightweight foamed concrete; meanwhile, the highest percentage of

porosity is 66.1% and 18.2% for 800 and 1600 kg/m³ respectively with inclusion 0.2% of sisal fibre. The porosity is affected by the addition of sisal fibre in the lightweight foamed concrete. The lower density of lightweight foamed concrete, 800 kg/m³ will lead to a higher porous structure compared to the 1600 kg/m³ density. A lower density of lightweight foamed concrete has a high quantity of foam to permit huge amounts of air pores to attain a higher porosity. The vast amount of foam also limits the binding of materials with a lower density of lightweight foamed concrete. Though, the existence of sisal fibre enhances the matrix in the lightweight foamed concrete. The reduction in porosity in this research ranges between 0.7–5.5%, which is very small and insignificant. The modification and morphology variant of the sisal fibre initiates the reduction in porosity

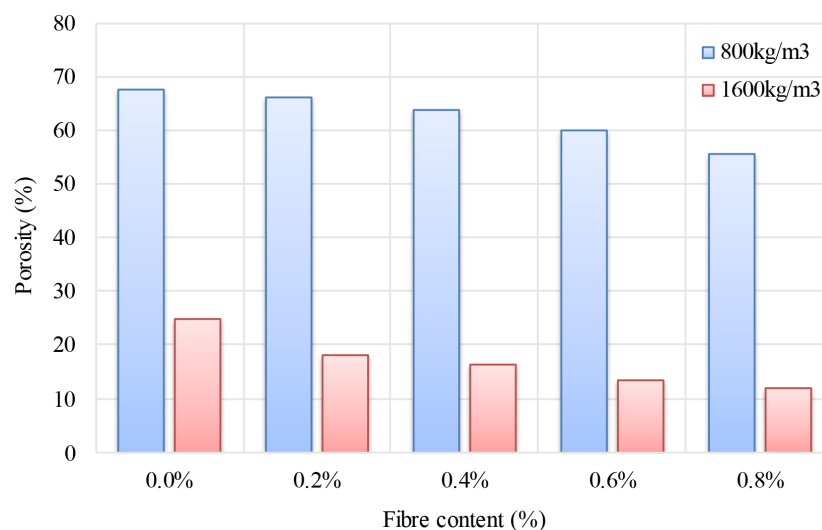


Fig. 6. Porosity of foamed concrete of different weight fraction of sisal fibre

of lightweight foamed concrete [11]. The greater weight fraction of fibre in cementitious composite aid to connect the matrix consequently lowering the porosity of lightweight foamed concrete [12].

### Drying shrinkage

As been demonstrated in Figures 7 and 8, drying shrinkage was drastically increased day-1 until day-28 and started constant reading on day-28 until day-60 for both densities considered in this study. The control specimens showed the highest drying shrinkage compared to the specimens with the inclusion of sisal fibre. As can be seen in Figures 7 and 8, the lowest value of drying shrinkage contained 0.6% of sisal fibre in lightweight

foamed concrete, followed by 0.4%. 0.8% and 0.2%. Lightweight foamed concrete with the addition of sisal fibre has an enhancement in drying shrinkage of the concrete. The factor that impacted the shrinkage performance is caused by the increase of foam content in the concrete. This is because cement paste usage will be reduced when a higher amount of foam is used [13]. Furthermore, the improvement of drying shrinkage is also triggered by the addition of sisal fibre where there is the absence of aggregates, and sisal fibre also contributes to improving the cement matrix [14]. Simultaneously, it also benefits to lower the creation and pattern of the crack. Hence it can be concluded that the drying shrinkage can be reduced by the presence of sisal fibre.

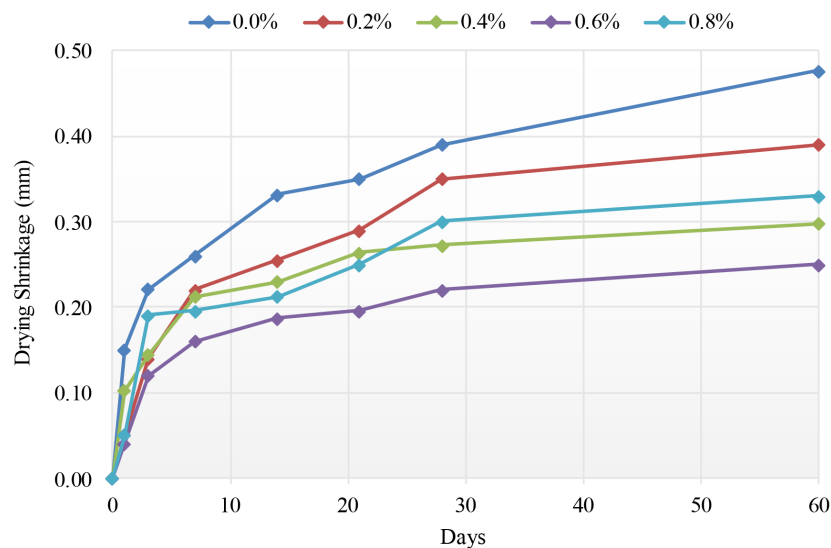


Fig. 7. Drying shrinkage of 800 kg/m<sup>3</sup> density with different weight fraction of sisal fibre

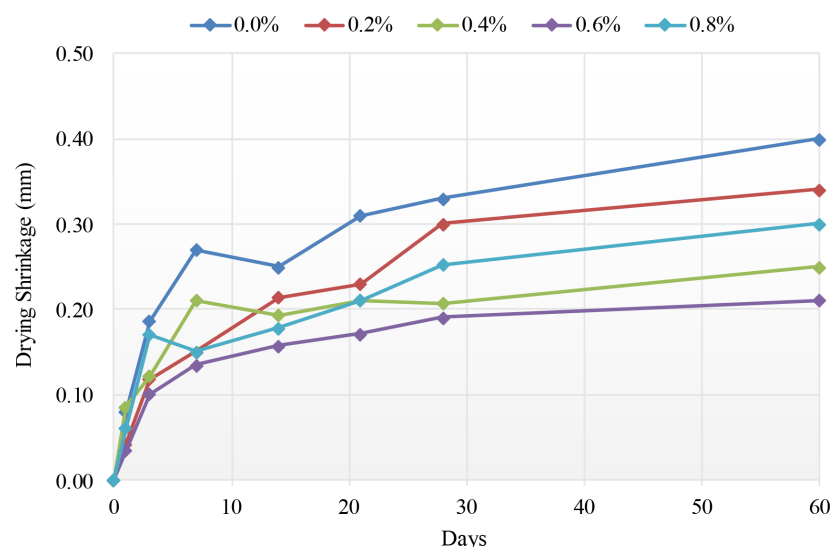


Fig. 8. Drying shrinkage of 1600 kg/m<sup>3</sup> density with different weight fraction of sisal fibre

### Ultrasonic Pulse Velocity (UPV)

Figure 9 displays the outcomes of the UPV test on both densities. The trend of the UPV is increasing with the increase of sisal fibre weight fractions. It can be observed that the inclusion of 0.6% of sisal fibre in the foamed concrete resulted in the highest value of UPV, which is 1690 m/s and 2399 m/s for 800 and 1600 kg/m<sup>3</sup> respectively compared to the control mixes, which have the lowest reading of UPV of 1460 m/s (800 kg/m<sup>3</sup>) and 2203 m/s (1600 kg/m<sup>3</sup>). As mentioned before, the results of UPV are influenced by the presence of voids and heterogeneity in lightweight foamed concrete. Thus, the pulse will be travel faster with high velocity when the lightweight foamed concrete is more elevated in density [15]. At the same time, it will reduce the time travel if it detects any

sign of deformity of the concrete. Therefore, it can be decided that the inclusion of sisal fibre ensued in more considerable readings of UPV.

### Correlation between porosity and water absorption

Figure 10 depicts the correlation between porosity and water absorption of both densities (800 and 1600 kg/m<sup>3</sup>). The foamed concrete was added with different percentages of sisal fibre by mix. Figure 10 evidently reveals there was a scatter of result water absorption and porosity. The R<sup>2</sup> value is 0.9603 which implies the relationship between both results, where the linear line represents the best trend correlation between water absorption capacity and the porosity. If the porosity increase, the water absorption also rises. The

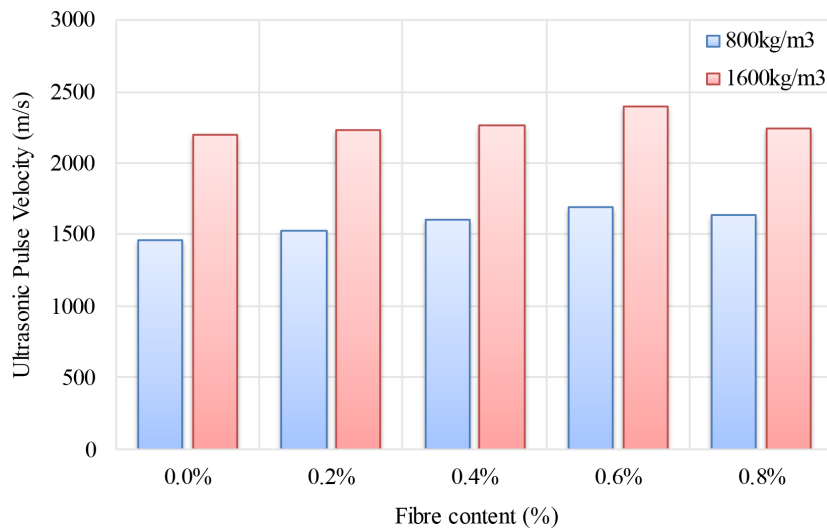


Fig. 9. UPV of foamed concrete with different weight fractions of sisal fibre

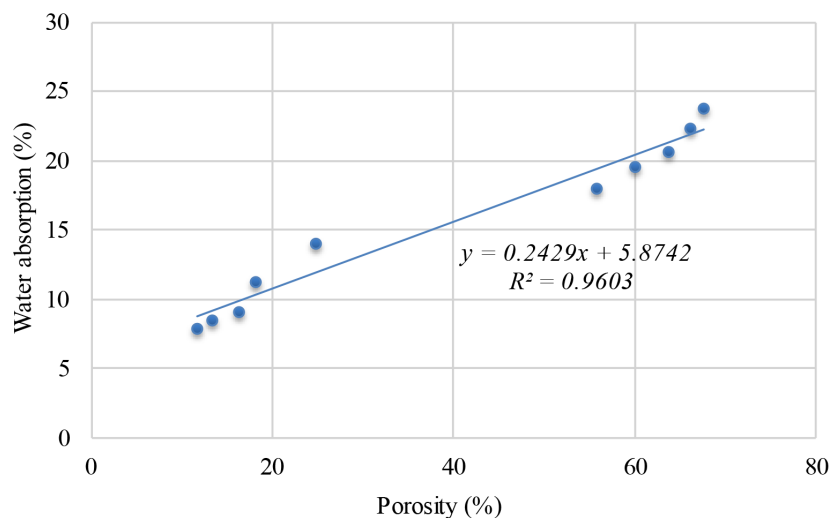
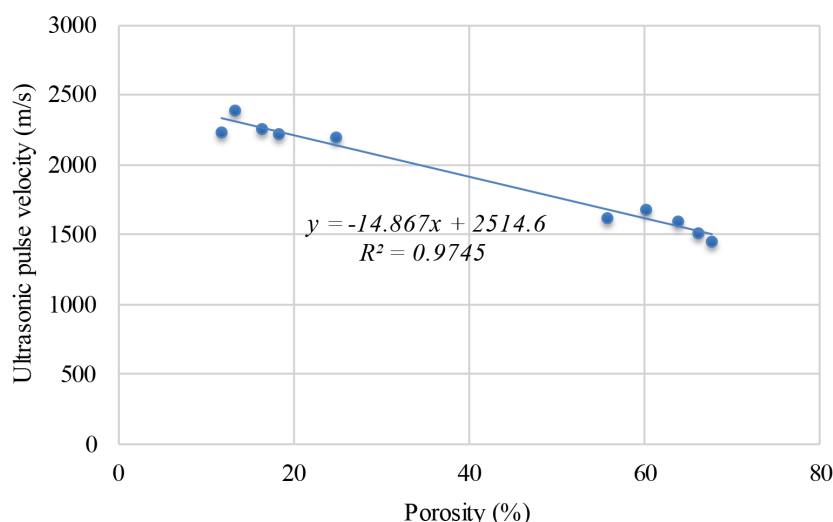


Fig. 10. Correlation between water absorption capacity and porosity of lightweight foamed concrete



**Fig. 11.** Correlation between porosity and UPV of lightweight foamed concrete

result of the linear line proved that the water absorption is directly proportional to porosity. It can be concluded that lightweight foamed concrete density absorbs more water and decrease durability. Both water absorption and porosity are inspired by the void formation of lightweight foamed concrete cement paste [16].

### Correlation between porosity and ultrasonic pulse velocity (UPV)

Figure 11 shows the correlation between UPV of lightweight foamed concrete with various weight fractions of sisal fibre. The linear line depicts the connection between UPV and porosity, where the  $R^2$  value is shown in the figure (0.9745). The value of  $R^2$ , which is near one is described the close relationship between UPV and porosity. Figure 11 demonstrates that UPV is diminishing along with the decreasing of porosity. UPV disparity between dry and saturated state is because the shape of pores has been changed with the moisture entering the material. The result showed that the higher porosity, the lower the UPV of lightweight foamed concrete. This means that the addition of sisal fibre showed an improvement in porosity value and UPV. The lower travel time is correlated to the high quality of lightweight foamed concrete with fewer irregularities.

### CONCLUSIONS

This research focuses on the durability performance of lightweight foamed concrete with

the addition of different weight fractions of sisal fibre. Two densities of 800 and 1600 kg/m<sup>3</sup> were made and assessed, with different weight fractions of sisal fibre (0.0%, 0.2%, 0.4%, 0.6% and 0.8%). The study revealed that the inclusion of a 0.6% weight fraction of sisal fibre gave the most excellent results for entire durability parameters tested (shrinkage, UPV, porosity and water absorption capacity). At 0.6% weight fraction, the sisal fibres and the cement matrix reached full compaction, which stemmed in decent mix uniformity. Further than the ideal percentage of sisal fibre inclusion, accretion and non-regular spreading of fibres took place, which led to a decline in entire durability parameters assessed.

### REFERENCES

1. Elshahawi M., Alex H., Mike S. Infra lightweight concrete: A decade of investigation (a review). *Structural Concrete*. 2021; 22: E152-E168.
2. Mydin, M.A.O. Preliminary studies on the development of lime-based mortar with added egg white. *International Journal of Technology*. 2017; 8(5), 800-810.
3. Serri E., Othuman Mydin M.A., Suleiman M.Z. Thermal properties of Oil Palm Shell lightweight concrete with different mix designs. *Jurnal Teknologi*. 2014; 70(1): 155-159.
4. Jones M.R., Zheng L., Ozlutas K. Stability and instability of foamed concrete. *Magazine of Concrete Research*. 2016; 68(11): 542-549.
5. Zhang Z., Provis J.L., Reid A., Wang H. Geopolymer foam concrete: An emerging material for sus-



- tainable construction. *Construction and Building Materials*. 2014; 56: 113–127.
6. Amran Y.H.M., Farzadnia N., Abang Ali A.A. Properties and applications of foamed concrete; a review. *Construction and Building Materials*. 2015; 101: 990-1005.
7. Nensok Hassan M., Othuman Mydin M.A., Awang H. Fresh state and mechanical properties of ultra-lightweight foamed concrete incorporating alkali treated banana fibre. 2022; 84(1):117-128.
8. Raj B., Dhanya S., Mini K.M., Amritha R. Mechanical and durability properties of hybrid fiber reinforced foam concrete. *Construction and Building Materials*. 2020; 245: 118373.
9. Othuman Mydin M.A., Sahidun N.S., Mohd Yusof M.Y., Noordin N.M. Compressive, flexural and splitting tensile strengths of lightweight foamed concrete with inclusion of steel fibre. *Jurnal Teknologi*. 2015; 75(5): 45-50.
10. Asim M., Ghulam M.U, Hafsa J., Ali R., Uzair H., Aamir N.S., Nasir H., Syed M.A. Comparative experimental investigation of natural fibers reinforced light weight concrete as thermally efficient building materials. *Journal of Building Engineering*. 2020; 31: 101411.
11. Norgaard J., Othuman Mydin M.A. Drywall thermal properties exposed to high temperatures and fire condition. *Jurnal Teknologi*. 2013; 62(1): 63-68.
12. Gencel O., Oguz M., Gholampour A., Ozbakkaloglu T. Recycling waste concretes as fine aggregate and fly ash as binder in production of thermal insulating foam concretes. *Journal of Building Engineering*. 2021; 38: 102232.
13. Mydin, M.A.O., Rozlan, N.A, Md Sani N., Ganesan S. Analysis of micro-morphology, thermal conductivity, thermal diffusivity and specific heat capacity of coconut fibre reinforced foamed concrete. *MATEC Web of Conferences*. 2014; 17: 01020.
14. Sang G., Yiyun Z., Gang Y., Haobo Z. Preparation and characterization of high porosity cement-based foam material. *Construction and Building Materials*. 2015; 91: 133-137.
15. Mydin, M.A.O, Musa M., Abdul Ghani A.N. Fiber glass strip laminates strengthened lightweight foamed concrete: Performance index, failure modes and microscopy analysis. In *AIP Conference Proceedings*. 2018; 2016(1): 020111.
16. Benmansour N., Boudjemaa A., Abdelkader G., Abdelhak K., Aberrahim B. Thermal and mechanical performance of natural mortar reinforced with date palm fibers for use as insulating materials in building. *Energy and Buildings*, 2014; 81: 98-104.