Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Thermal and Durability Properties of Sustainable Green Lightweight Foamed Concrete Incorporating Eco-Friendly Sugarcane Fibre

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ARTICLE INFO

Article history:
Received 27 January 2022
Received in revised form 15 March 2022
Accepted 20 March 202
Available online 3 April 2022

Keywords:
Lightweight foamed concrete; thermal conductivity; diffusivity; specific heat capacity; water absorption

ABSTRACT

Efforts to modify cement-based mixtures have always enticed the interest of researchers. Lightweight foamed concrete is immensely porous, and its properties diminish with increasing in the number of pores. To enhance its properties, the solid matrix of LFC can be attuned by integrating numerous natural fibres. The influence of eco-friendly sugarcane fibre in LFC was not investigated before in the current body of knowledge. Hence, there is some ambiguity considering the mechanism by which and the extent to which the sugarcane fibre can influence LFC properties. Therefore, this study concentrates on distinguishing the potential use of sugarcane fibre into lightweight foamed concrete. This study aims to determine the durability and thermal properties of LFC with the addition of sugarcane fibre. Low density of 800kg/m^3 were cast and tested. Different weight fractions of sugarcane fibre of 0.15%, 0.30%, 0.45% and 0.60% were used. For durability properties, four parameters were appraised such as water absorption capacity, porosity, drying shrinkage, ultrasonic pulse velocity. While for thermal properties were assessed which were thermal conductivity, thermal diffusivity and specific heat capacity. Protein-based foaming agent Noraite PA-1 was utilized to produce the desirable density of LFC. To get the comparable results, the water to cement ratio was fixed to 0.45 while the cement to sand ratio constant at 1:1.5. The results had indicated that the addition of 0.45% of sugarcane fibre gave the optimum results for all the durability and thermal properties considered in this research. At 0.45% weight fraction of SF, the fibres and the cementitious matrix achieved maximum compaction, which stemmed in excellent mix homogeneity. Beyond the optimum level of sugarcane fibre inclusion, agglomeration and the non-uniform dispersion of fibres was observed, which led to decrease in entire durability and thermal properties appraised.

1. Introduction

Construction industry in Malaysia has shown major appreciation in the use of lightweight foamed concrete as a building material owing to its various encouraging attributes such as lighter in weight, easy to manufacture, cost effective and robust [1]. Lightweight foamed concrete can be defined as a lightweight material consisting of ordinary Portland cement with a homogeneous pore structure created by introducing air in the form of small bubbles. With precise mechanism in the amount of

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https://doi.org/10.37934/arfmts.94.1.6078

foam and techniques of production, a broad scale of lightweight foamed concrete densities starting from 600 to 1800 kg/m^3 can be produced [2]. Worldwide interest of eco-friendly building materials has propelled a lot of research on green concrete globally [3]. Awareness has been given to areas such as concrete mix design, mix material sourcing, construction method, construction technology, and concrete structure maintenance [4].

Therefore, accomplishing sustainable development in society depends on the significant role played by the industry players [5]. Generally, most of the construction materials are manufactured from non-sustainable products that need a high amount of energy to cause a global problem. Thus, plant fibre in lightweight foamed concrete can be utilized in concrete production, contributing to unravelling these difficulties [6]. There are several benefits when using lightweight foamed concrete in construction, such as delivering good thermal insulation, exceptional fire resistance, lightweight and decrease few materials in concrete like cement, fine aggregates, stable foam, and water. These materials are common of lightweight foamed concrete. Another admixture can be added to it to improve the strength of lightweight foamed concrete [7].

Lightweight foamed concrete become lighter due to the absence of aggregates and this type of concrete also known as high workability, low cement content and less aggregate usage. Besides, it also can be classified as eco-friendly, easy to produce and flammable. Still, to mix it, a longer time is needed to ensure the materials are correctly mixing to obtain the targeted density of lightweight foamed concrete [8]. The integration of fibre into LFC improves the strength and durability of lightweight foamed concrete. Meanwhile, it has been shown that a low volumetric of the short fibre reduces the effect of early age on the durability of concrete [9]. The advancement in the prominence of surfactants such as foaming agents and foam generators allows the larger scale in applying the lightweight foamed concrete act as the roof insulation, floor screed ad concrete blocks.

It is essential to identify the number of fibres, cement, sand, water, and foaming agent in the mixture. 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 [10]. Natural fibres can be used to reinforce cementitious materials, particularly when developing and fabricating building materials. There were some efforts by several researchers to establish thermal and durability properties of lightweight foamed concrete strengthened with natural and synthetic fibres. Mydin *et al.,* [11] embarked on research efforts using coir fibre in lightweight foamed concrete inclusion of coir fibre in lightweight foamed concrete lessens thermal diffusivity and conductivity but improves the composites' specific heat capacity. Comparable research endeavours were performed using steel fibre. The study revealed that the lightweight foamed concrete composites' thermal conductivity and thermal diffusivity rise with an increase in the steel volume fraction compared to the control specimen. These two results mean that while coir plant fibre enhances lightweight foamed concrete thermal properties, steel fibre helps lessen lightweight foamed concrete thermal performance. Awang and Ahmad [12] commenced a comparative study of synthetic and natural fibres at fibre volume fraction of 0.25% and 0.40%. They utilized steel, glass, oil palm, kenaf and polypropylene fibres. They found that polypropylene fibre behaves well in terms of thermal properties, followed by kenaf fibre, oil palm fibre, glass fibre, and lastly, steel fibre correspondingly. The study also suggests that the thermal properties lightweight foamed concrete improved with the increase in the fibre volume fraction. Latest research efforts by Raj *et al.,* [13] assessed the performance of lightweight foamed concrete strengthened with coir fibre and polyvinyl alcohol fibre. They found that lightweight foamed concrete strengthened with coir fibre performs better than that strengthened with polyvinyl alcohol fibre, which provides better than lightweight foamed concrete strengthened with the two fibres’ hybrid composites.

From the above review, the influence of sugarcane fibre inclusion in lightweight foamed concrete for thermal and durability properties enhancement is not well studied and understood. Therefore, this study focuses on determining the thermal and durability properties of lightweight foamed concrete reinforced with sugarcane fibre. Lightweight foamed concrete density of 800 kg/m^3 was fabricated with different weight fractions of sugarcane fibre and the composites' thermal and durability properties were examined.

2. Methodology

For this study, there was a total of five lightweight foamed concrete mixes of 800kg/m^3 density were produced. The weight fraction of sugarcane fibre (SF) employed in this appraisal were 0.15%, 0.30%, 0.45% and 0.60%. A control lightweight foamed concrete without any addition of SF was also prepared for comparison purpose. The range of SF weight fraction between 0.15% to 0.60% had been chosen in this research was because during the pilot study, the researcher had found that the inclusion of SF weight fraction of more than 0.6% led to agglomeration and non-uniform dispersion of SF during mixing process. The sand to cement ratio used was 1:1.5 and the water-cement ratio applied was kept constant at 0.5 for all the mixes. Table 1 illustrates the mix proportions of this study.

Table 1
Mix design proportion

Specimen	Dry Density (kg/m^3)	Ratio (*c:w:s)*	Sugarcane fibre (kg)	Cement (kg)	Sand (kg)	Water (kg)
Control	800	1:1.5:0.5	-	30.25	45.37	13.61
0.15% SF	800	1:1.5:0.5	0.134	30.25	45.37	13.61
0.30% SF	800	1:1.5:0.5	0.268	30.25	45.37	13.61
0.45% SF	800	1:1.5:0.5	0.402	30.25	45.37	13.61
0.60% SF	800	1:1.5:0.5	0.535	30.25	45.37	13.61

Ordinary Portland Cement was used in accordance with BS12 Standard which was distributed by YTL Castle Cement. All the cement used was in excellent condition and kept in a protected area. Then, the filler used was natural fine sand acquired from a local distributor. The sand was fine with a maximum width of 2mm and a 600-micron sieve, and a passage of 60% to 90%. The suitability of the sand had to follow BS822. The foaming agent used was a protein-based foaming agent, namely Noraite PA-1. This Noraite PA-1 was chosen as the foaming agent due to its stability and smaller bubbles, which create a stronger bubble bonding structure compared to a synthetic-based protein.

Next, the tap water used had to be clear and clean. Water was required for the preparation of the mortar, mixing the LFC and the curing work. The water-cement ratio used for this research was 0.45, because this ratio can accomplish reasonable workability, based on previous research. Finally, the fibre used was SF, which was freshly collected from an industrial unit after processing. The SF was covered by a skin of grease which would cause fungus growth and spoilage. The SF needed to be washed until it was free from the grease. The SF was placed under the sun to dry.

Table 2, Table 3 and Table 4 show the chemical composition, mechanical properties and physical properties of SF respectively. SF had high cellulose percentage which may assist significantly when in composite action with lightweight foamed concrete cementitious matrix. Natural plant fibres like SF with high cellulose content, typically, present a low deformation capacity with excellent young's modulus and this is confirmed by the experimental evidence attained in the study. Additionally, it was testified that commonly the tensile strength and young's modulus of plant fibre improves with improving cellulose content of the SF.

Table 2
Chemical composition of sugarcane fibre

Composition	%, dry weight
Lignin (%)	18.1
Cellulose (%)	46.8
Hemicellulose (%)	29.8
Ash (%)	5.3

Table 3
Mechanical properties of sugarcane fibre

Component	Properties
Tensile strength (MPa)	128.5
Young's modulus (MPa)	13500
Elongation at break (%)	9.15

Table 4
Physical properties of sugarcane fibre

Component	Properties
Fibre length	19mm
Fibre diameter	242 um
Lumen width	14.76 um
Density	0.92 g/cm^3

3. Experimental Setup

3.1 Water Absorption Test

Water absorption test was accomplished in line with BS 1881: Part 122 on 75mm diameter x 100mm height size 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 placed in an oven at 105°C for 72 hours to make sure that the specimens were fully dry prior the water absorption test. The calculation of water absorption as below:

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

where,
W_a = *Water absorption*
W_{sat} = *Saturated surface dry weight of foamed concrete*
W_{dry} = *Oven-dried weight of specimen*
W_{wet} = *Weight of sample in water*

3.2 Porosity Test

Porosity of specimens were established via Vacuum Saturation Apparatus. The dried specimens were placed under a vacuum in a desiccator for three days. During that time, the desiccator filled with de-aired and distilled water. The specimens were placed in a ventilated oven set to 105°C for three days to identify oven-dry mass. After that, the specimens were removed from the oven and cooled at room temperature. The objective of measuring the specimens' weight is to determine their oven-dray mas 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. The porosity of lightweight foamed concrete is determined using the equation below:

$$Pr = \frac{Wsat - Wdry}{Wsat - Wwet} x\ 100\% \tag{2}$$

where,
P_r = Porosity
W_{sat} = Saturated surface dry weight of foamed concrete
W_{dry} = Oven-dried weight of specimen
W_{wet} = Weight of sample in water

3.3 Drying Shrinkage

Drying shrinkage test was accomplished in line with AASTM C878. A 75mm with length 250mm prism was used with an estimated overall length of 290mm, including the rod and cap nuts. 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 250m invar bar which capable of adjusting the measurement up to 0.001mm. The comparator's length was adjusted against a reference invar for each specimen. The drying shrinkage is established using the equation as below:

$$L = \frac{Lx - Li}{G} x\ 100 \tag{3}$$

where,
L = Change in length
L_x = Difference between the comparator reading at age X
L_i = Initial reading
G = Gauge length

3.4 Ultrasonic Pulse Velocity Test

The test was performed by assessing the transmission velocity of a transmitted longitudinal ultrasonic pulse across the cross- sectional area. Mortar prisms were measured at the dimensions of 100mm x 100mm x 500mm. An electro-acoustical transducer was used to examine transmission of the ultrasonic pulse It is held in contact into an electrical signal by a second transducer after the pulse traversing a known path length in the specimen. Electromagnet transducer was then showed the transmitted time and velocity. The standard procedures were conducted according to the standard prescribed in BS EN 12504-4. A mortar prism with the dimensions of 100mm x 100mm x500mm was constructed for all mix designs and examined at day 7, day 28, day 60 and day 180 during the curing stage. Readings were taken and the average velocity of the UPV result was taken.

3.5 Thermal Test

The hot disk thermal constant analyser by adapts the Transient Plane Source (TPS) method by refer to the BS EN ISO 22007-2:2015 was utilised to measure thermal diffusivity, specific heat capacity and thermal conductivity during the test. The censor used was sandwiched between the 2 samples. Size of the sample used was 25 x 50 mm with 10 mm of thickness. All specimens that will be tested need to be in dry state condition. Data such as probing depth, time and power used need to be set until constant and allowable rate was accepted. The thermal conductivity, diffusivity, and specific heat capacity of lightweight foamed concrete strengthened with sugarcane fibre were determined using the hot disk thermal constant analyser. This thermal constant analyser can assess within a short period the thermal conductivity (W/mK), thermal diffusivity (mm^2/s), and specific heat capacity (MJ/m^3K) of material all at once and gives the reading directly. The specimens for each test were obtained after 28 days of curing the batch mixes using carefully cut samples of 40 x 40 x 20 mm. After cutting the samples in pairs, the samples are smoothened, sandpapered, blown with the air blower, and dried. Two samples of identical dimensions are first put in the oven at 75±5°C for 72 hours or until constant weight to remove the moisture in them altogether. Two samples of identical dimensions are used to sandwich a constant thermal analyser sensor.

4. Results and Discussion

4.1 Water Absorption

Figure 1 demonstrates the water absorption results with the addition of a different weight fraction of SF in lightweight foamed concrete. It can be seen from Figure 1 that the water absorption decreased as the weight fraction of SF in lightweight foamed concrete increased. The decreasing trend is due to the inclusion of SF in LFC, in which 0.6% weight fraction SF inclusion led to lowest water absorption, which is 16.4%, compared to the inclusion of 0.15% SF by mix resulting in 19.3% water absorption value. Meanwhile, the second lowest of water absorption is 17.6% which contained 0.45% of SF in lightweight foamed concrete, followed with 0.30% of SF, which resulted in 18.6% water absorption value. This result indicates that lightweight foamed concrete has high water absorption because the low density of lightweight foamed concrete contains more foam, creating many air voids. As revealed, the lower density of LFC, $800kg/m^3$, has larger pores, which led to weak matrix corporation that can disrupt the quality of lightweight foamed concrete. Furthermore, 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 capacity of lightweight foamed concrete. Lower rate of lightweight foamed concrete water absorption specifically when it contained higher SF weight fraction compared to lower SF weight fraction was due to reduction of the size of capillary pores with the addition of higher weight fraction of SF. Higher content of plant fibre managed to block water from penetrating into concrete due to small size of pores and volume [14]. Meanwhile, the SF lost its dampness and shrunk back onto their sizes due to drying process. Additionally, the C-S-H gel creation in matrix of concrete with higher content of fibre condensed the pore size, which resulted in lower water absorption [8].

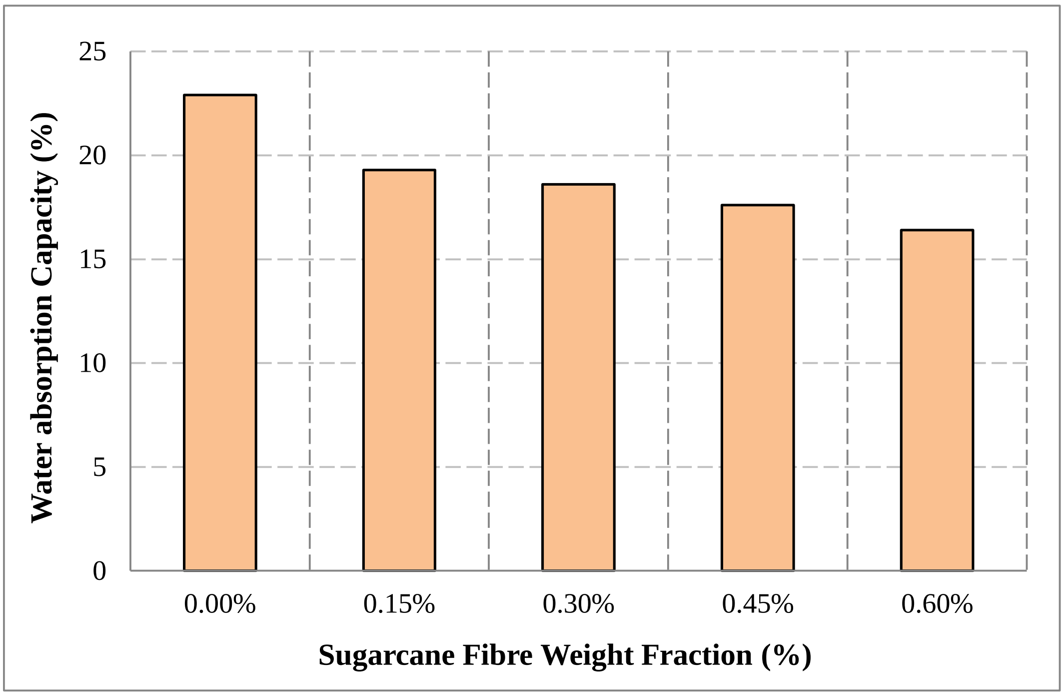

Fig. 1. Water absorption of foamed concrete with different sugarcane fibre weight fraction

4.2 Porosity

Figure 2 shows the percentage of porosity of lightweight foamed concrete with various weight fraction of SF. The trend of porosity is decreasing along with the increase of SF in the lightweight foamed concrete. The results show that the lowest percentage of porosity is 60.1% which contained 0.6% weight fraction of SF in lightweight foamed concrete; meanwhile the highest percentage of porosity is 67.6% with inclusion 0.15% of SF. Figure 2 also revealed that 0.45% and 0.30% of SF in lightweight foamed concrete result in 63.8% and 66.1% of porosity, respectively. The percentage of porosity is affected by the addition of SF in the lightweight foamed concrete. The lightweight density of lightweight foamed concrete, 800kg/m^3 will lead to a higher porous structure. A lower density of lightweight foamed concrete has a high quantity of foam to allow large amounts of air voids to achieve a higher porosity value. The immense amount of foam also limits the binding of materials with a lower density of lightweight foamed concrete. However, the presence of SF improves the matrix in the lightweight foamed concrete at once; it improves the compressive strength. The reduction in porosity with the addition of natural fibres reported in this study ranges between 1.1%-6.3%, which is very small and negligible. On another note, the alteration and morphology variation of the SF triggers the reduction in porosity of lightweight foamed concrete [15,16]. Higher volume fraction of fibre in concrete assist to bridge the matrix hence reducing the porosity of lightweight foamed concrete [17,18].

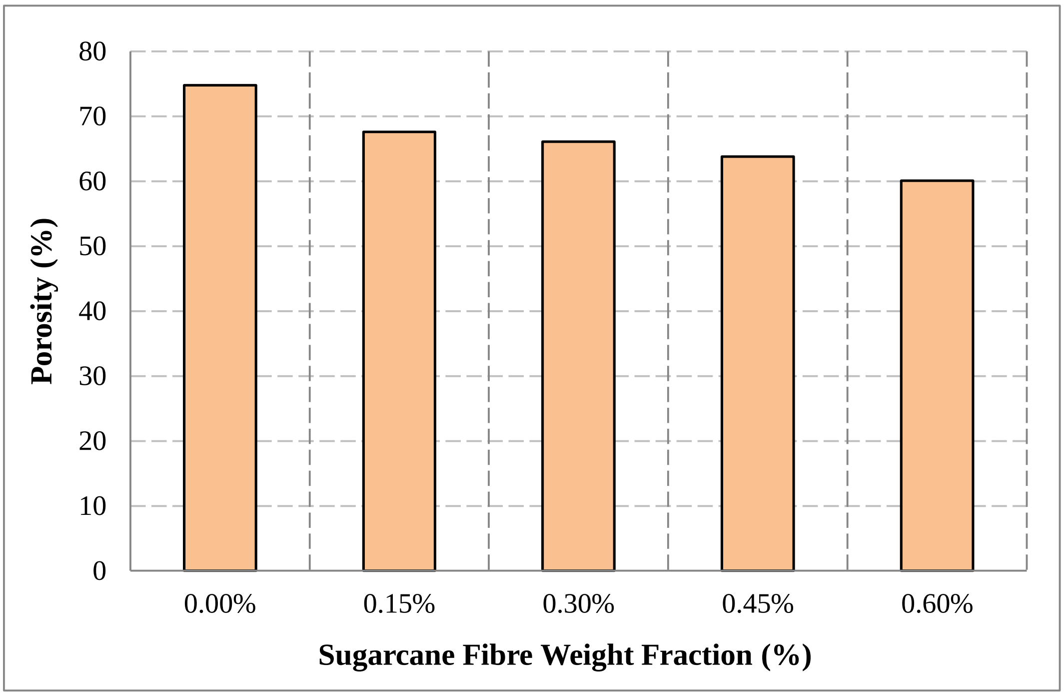

Fig. 2. Porosity of foamed concrete of different weight fraction of sugarcane fibre

4.3 Drying Shrinkage

Drying shrinkage can be defined as the contracting of the concrete mixture because of the loss of water. The drying shrinkage tests able to determine the expansion of concrete. This shrinkage can cause tensile stress increase and lead to cracking when subjected to the load. So that, this experimental test is to explain the ability of SF to resists the changes in volume in concrete. Based on the Figure 3, all the specimens are drastically increased day-1 until day-28 and start constant reading on day-28 until day-60. The control specimens show the highest reading compared to the specimens with SF in lightweight foamed concrete with a density of 800kg/m^3. Furthermore, the lowest value of drying shrinkage contained 0.45% of SF in lightweight foamed concrete, followed by 0.60%. 0.30% and 0.15%. Lightweight foamed concrete with the addition of SF has an improvement in shrinkage of the concrete. The factor that affected the shrinkage behavior 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 [19]. Additionally, the reduction of drying shrinkage also caused by the addition of SF where there is the absence of aggregates, and SF also contributes to improving the cement matrix [20]. At the same time, it also helps to lower the cracks of the lightweight foamed concrete. So that it can be concluded that the drying shrinkage can be reduced by the addition of SF in foamed concrete.

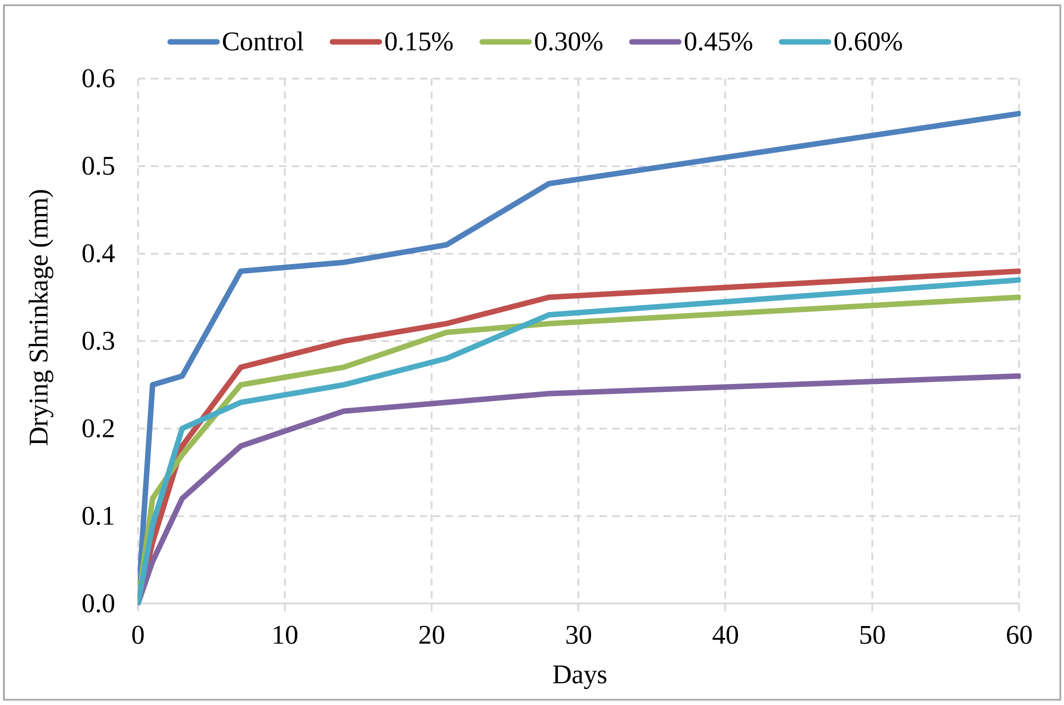

Fig. 3. Drying shrinkage of foamed concrete with different weight fraction of sugarcane fibre

4.4 Ultrasonic Pulse Velocity

The purpose of the ultrasonic pulse velocity test is to evaluate the strength of lightweight foamed concrete. It also can detect the presence of voids, honeycombing, or any discontinuities in the lightweight foamed concrete. The velocity of ultrasonic energy is affected by the mechanical strength where it identifies the heterogeneous regions in the lightweight foamed concrete. The higher velocity results can be obtained when the quality of lightweight foamed concrete is good in terms of homogeneity and density. Figure 4 shows the results of the ultrasonic pulse velocity test on the specimens of 800kg/m^3 lightweight foamed concrete. The trend of the ultrasonic pulse velocity is increasing with the increase of SF in the lightweight foamed concrete. It can be observed that the inclusion of 0.6% of SF in the lightweight foamed concrete resulted in the highest reading of ultrasonic pulse velocity, which is 1559 m/s compared to the control mixes, which have the lowest reading of ultrasonic pulse velocity 1387 m/s. The result of ultrasonic pulse velocity was obtained for 0.15%, 0.30%, and 0.45% in addition to SF in lightweight foamed concrete, where it has 1442 m/s, 1477 m/s, and 1508 m/s, respectively. As mentioned before, the results of ultrasonic pulse velocity are influenced by the presence of voids and heterogeneity in lightweight foamed concrete. Therefore, the pulse will be travel faster with high velocity when the lightweight foamed concrete is more elevated in density [21]. At the same time, it will reduce the time travel if it detects any sign of deformity of the lightweight foamed concrete. Therefore, it can be concluded that the addition of SF resulted in more significant readings of ultrasonic pulse velocity value.

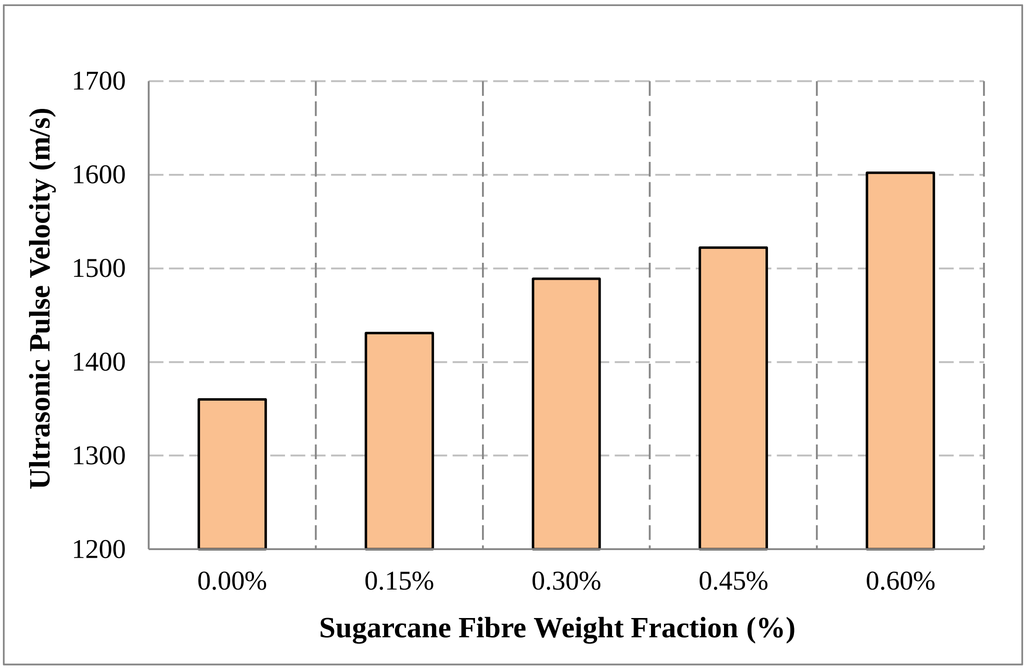

Fig. 4. Ultrasonic pulse velocity of foamed concrete with different weight fraction of sugarcane fibre

4.5 Relationship between Water Absorption and Porosity

Figure 5 below depicts the relationship between water absorption with porosity for lightweight foamed concrete with a density of 800kg/m^3. The lightweight foamed concrete was added with different percentage of SF by mix. The graph below clearly shows there was a scatter of result water absorption and porosity. The R2 value is 0.99 which indicates the relationship between both results, where the linear line represents the best trend relationship between water absorption and porosity. If the porosity increase, the water absorption also rises. The result of the linear line proved that the water absorption is directly proportional to porosity. It can be concluded that lightweight lightweight foamed concrete density absorbs more water and decrease durability. Both water absorption and porosity are inspired by the pore structure of lightweight foamed concrete cement paste [22].

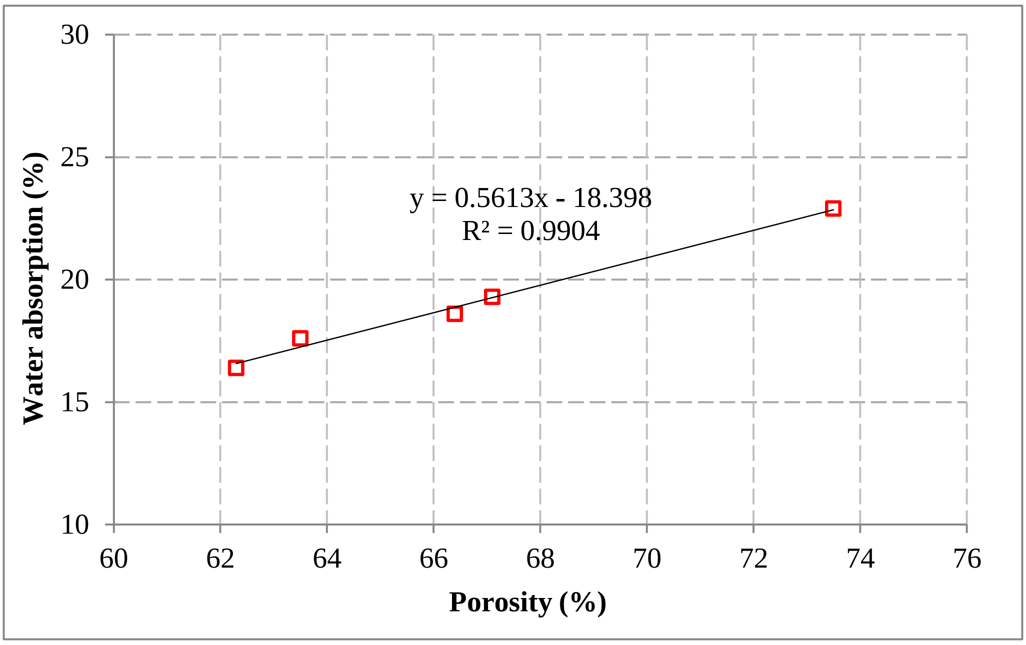

Fig. 5. Relationship between water absorption and porosity of lightweight foamed concrete

4.6 Relationship between Porosity and Ultrasonic Pulse Velocity

Figure 6 shows the correlation of lightweight foamed concrete 800kg/m^3 with various weight fraction of SF. The linear line depicts the connection between ultrasonic pulse velocity and porosity, where the R2 value is shown in the figure. The value of R2, which is near one is explained the close relationship between ultrasonic pulse velocity and porosity. The graph demonstrates the ultrasonic pulse velocity is decreasing along with the decreasing of porosity. Ultrasonic pulse velocity variation between dry and saturated state is because the shape of pores has been changed with the moisture entering the material. The result in the graph proved that the higher porosity, the lower the ultrasonic pulse velocity value in the lightweight foamed concrete. This means that the addition of SF showed an improvement in porosity value and ultrasonic pulse velocity [23]. The lower travel time is correlated to the high quality of lightweight foamed concrete with fewer anomalies.

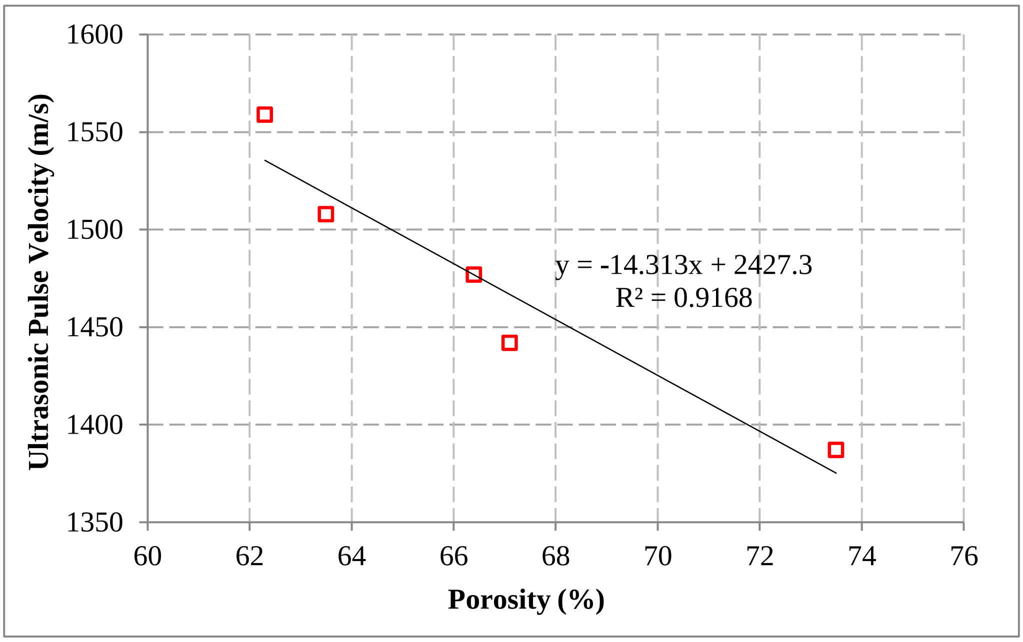

Fig. 6. Relationship between porosity and ultrasonic pulse velocity of lightweight foamed concrete

4.7 Thermal Conductivity

Figure 7 demonstrates the results of thermal conductivity of lightweight foamed concrete with different weight fractions of SF. This study had confirmed that inclusion of SF of all weight fractions led to improved thermal conductivity compared to the control specimen which had a thermal conductivity of 0.2167 W/mK. By adding 0.45% volume fraction of SF gave the best result of thermal conductivity. The recorded thermal conductivity was 0.1543 W/mK. However, the sample with 0.60% weight fraction of SF showed higher thermal conductivity compared to 0.45% weight fraction of SF. This may be due to non-uniform distribution of SF in lightweight foamed concrete once it achieved optimum volume fraction (0.45%). Reasons for the decrease in thermal conductivity as the SF volume fraction increases (up to the optimum weight fraction) are because of the porous nature of natural fibre and the lumen's presence. Other reasons for very low thermal conductivity in lightweight foamed concrete composites are the redistribution and creating a smaller uniform pore void due to the SF's addition. This phenomenon resulted in the production of a more multiple isolated pore void than the control where there is no fibre addition. The results also revealed that the SF has a great potential to be utilized in cement-based material like lightweight foamed concrete in which it can play an important role to reduce the thermal inducing property or heat transfer of produced concrete. Additionally, the produced lightweight foamed concrete from SF has an energy-saving prospective when it is applied as a green building material. Indeed, one of the green building necessities upheld in Malaysia is low energy consumption; hence if this composite material is used in concrete precast wall or non-load-bearing structure, it can insulate heat transfer from side to side better than the ordinary lightweight foamed concrete and help to lessen energy consumption from room temperature tuning.

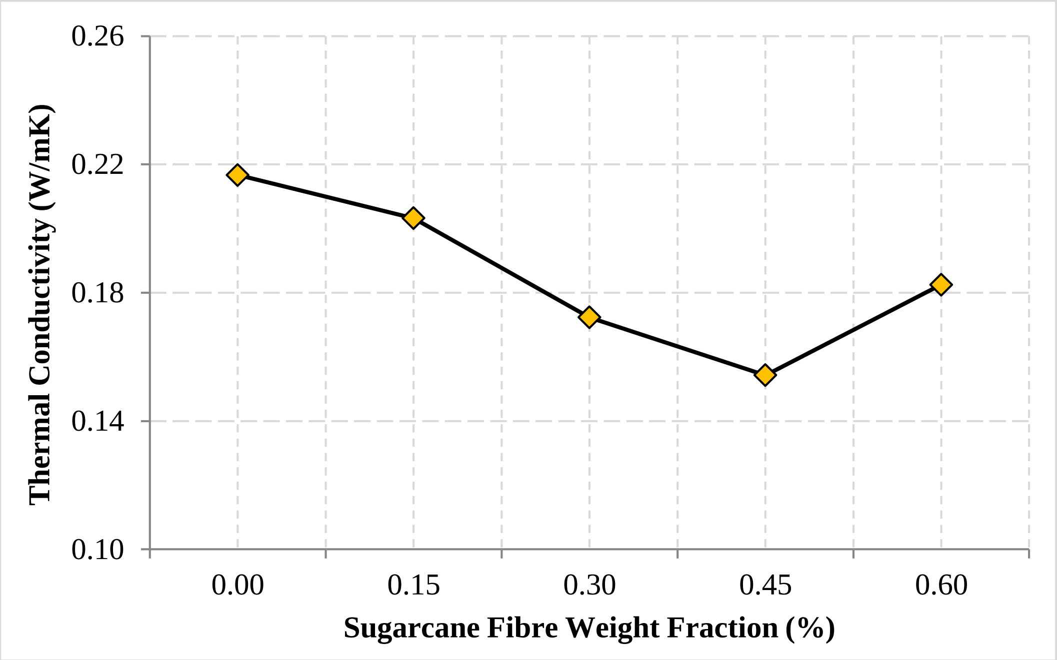

Fig. 7. Thermal conductivity of foamed concrete with different weight fraction of sugarcane fibre

4.8 Thermal Diffusivity

Figure 8 demonstrates the thermal diffusivity results of lightweight foamed concrete strengthened with different weight fractions of SF. Figure 8 indicates that as the weight fraction of SF increases, the thermal diffusivity increases as well. This was as a result found for thermal conductivity of the lightweight foamed concrete. As SF weight fraction of lightweight foamed concrete increases from 0.15%BF to, 0.30% to 0.45%, the thermal diffusivity increases from 0.3523, 0.3635 to 0.3788 m^2/sec, respectively. The incorporation of SF into lightweight foamed concrete aids to enhance the thermal diffusivity because of the low thermal conductivity of the SF and cellulose, hemicellulose and lignin. The fibrous nature of the fibre and lumen's presence further contributed to the porous fibre nature. The existence of SF high cellulose content of 46.8% (refer Table 2), the SF will promptly absorb water and have excellent wettability to enhance the composite's lightweight foamed concrete performance [21]. The thermal diffusivity of the lightweight foamed concrete material can be defined as the composite material's ability to conduct heat relative to the heat stored per unit volume. In other words, the thermal diffusivity of the lightweight foamed concrete is the measure of how fast heat can flow in the composite material. Consequently, if the heat flows within a composite's material very rapidly, the material is considered an excellent thermal conductor. In contrast, if the heat flows within a composite's material very slowly, the material is considered an excellent thermal insulator. In this case, the addition of the SF into lightweight foamed concrete enhances the rate of heat flow, thus making it an outstanding thermal insulator.

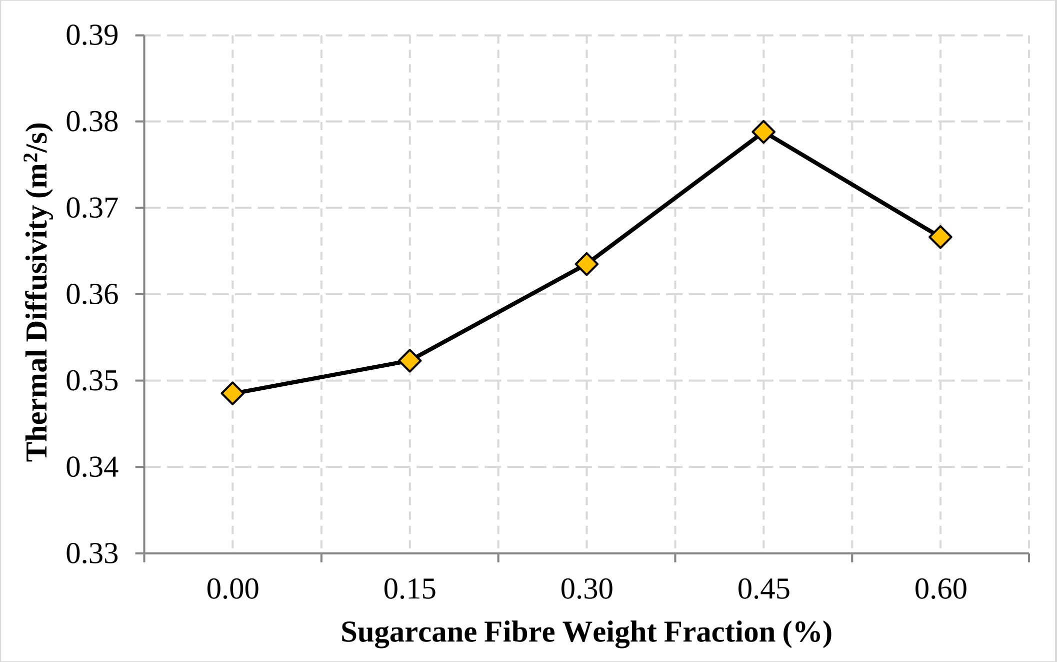

Fig. 8. Thermal diffusivity of foamed concrete with different weight fraction of sugarcane fibre

4.9 Specific Heat Capacity

Specific heat capacity is a measurement used for heat energy that absorbed or released by a substance in a unit quality in the case of temperature increases or decreases by 1K. More energy is needed when the specific heat energy of a material increases as to raise its temperature. Additionally, the ability of a material in retaining heat and in conserving energy in buildings is called a high specific heat. Specific heat capacity is very crucial in retaining the heat and thus contributing to the thermal mass of a material. Figure 9 reveals the specific heat capacity results of lightweight foamed concrete strengthened with different weight fractions of SF. This study had confirmed that inclusion of SF of all weight fractions led to reduced specific heat capacity compared to the control specimen which had a specific heat capacity of 0.5231 W/mK. By adding 0.45% volume fraction of SF gave the best result of specific heat capacity. The recorded specific heat capacity was 0.4028 W/mK. Though, the sample with 0.60% weight fraction of SF showed greater specific heat capacity compared to 0.45% weight fraction of SF. It is evident when the SF was added in lightweight foamed concrete, the specific heat of cement paste reduces (up to optimum weight fraction on 0.45%) due to the interface between cement and SF which contribute towards the specific heat components related to the element of vibrations.

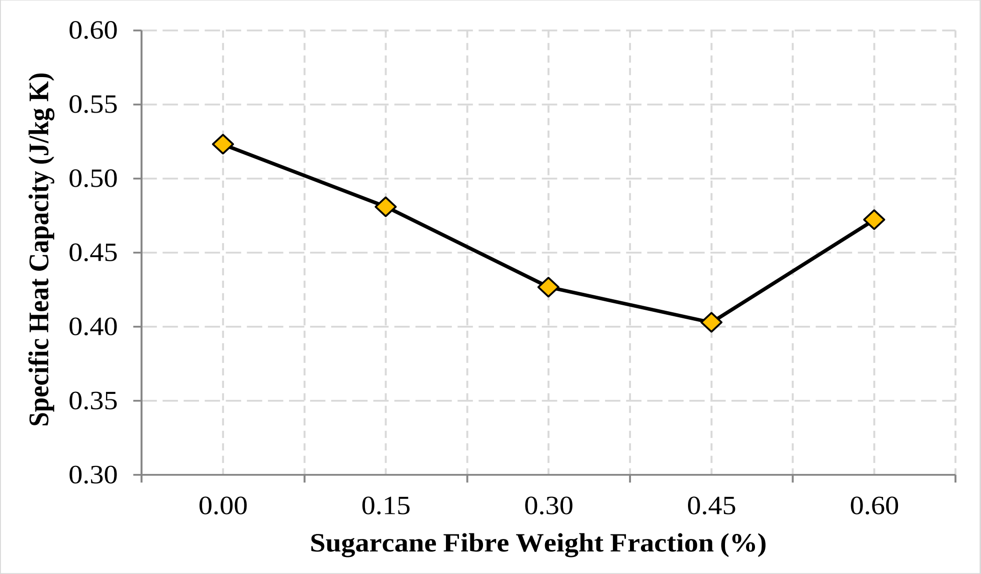

Fig. 9. Specific heat capacity of foamed concrete with different weight fraction of sugarcane fibre

4.10 Relationship between Thermal Conductivity and Thermal Diffusivity

Thermal conductivity and diffusivity play a crucial function in transferring the properties of cement-based material like lightweight. These two parameters are very important to understand the relations of fracture network in predicting the thermal conductivity of a porous media. Consequently, this assessment attempts to observe the interactions between thermal conductivity and thermal diffusivity of lightweight foamed concrete strengthened with SF. Figure 10 shows the correlation between thermal conductivity and thermal diffusivity of lightweight foamed concrete with the addition of SF. The direction of the line implies that as thermal conductivity declines due to an increase in SF weight fraction, thermal diffusivity increases. Similarly, an increase in thermal conductivity will equally result to a corresponding decrease in thermal diffusivity. The regression analysis presents the best inclinations in designating the relationship between thermal conductivity and thermal diffusivity which can be given as a linear function. The R2 value of 0.9311 depicts a strong correlation between the thermal conductivity and the thermal diffusivity for foamed concrete.

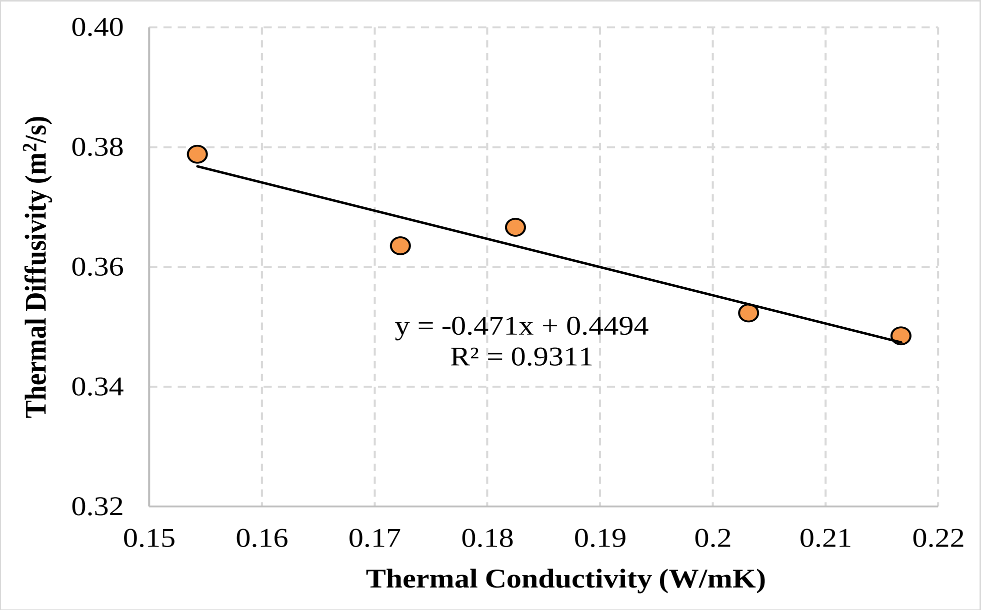

Fig. 10. Relationship between thermal conductivity and thermal diffusivity of foamed concrete

4.11 Relationship between Thermal Conductivity and Specific Heat Capacity

Figure 11 demonstrates the relationship between thermal conductivity and specific heat capacity of lightweight foamed concrete with the addition of SF. The regression analysis presents the best tendencies in specifying the relationship between thermal conductivity and specific heat capacity which can be presented as a linear function. The straight-line graph indicates an indirect variation between the thermal conductivity and the specific heat. In which case, as the thermal conductivity reduces due to SF weight fraction addition, the specific heat capacity increases. The R2 value of 0.9806 indicates a very strong correlation between the thermal conductivity and the specific heat capacity.

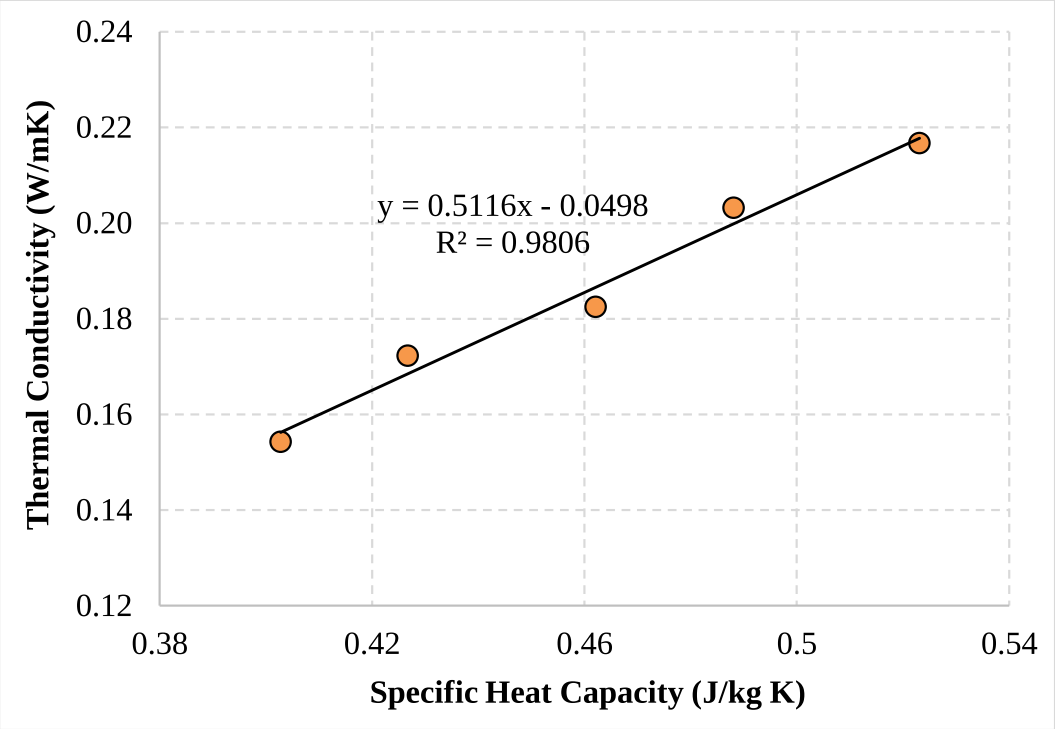

Fig. 11. Relationship between thermal conductivity and specific heat capacity of foamed concrete

4.12 Relationship between Thermal Diffusivity and Specific Heat Capacity

Figure 12 reveals the correlation between thermal diffusivity and specific heat capacity of lightweight foamed concrete with the addition of SF. The direction of the straight-line graph depicts that as thermal diffusivity increases due to fibre volume fraction, specific heat capacity declines. This consistently means that the addition of SF in lightweight foamed concrete results to a reduction in the values of specific heat capacity of the composites material. The regression equation for this relationship is shown in Figure 12. The R2 value for the regression equation is 0.9712, signifying a strong correlation between the thermal diffusivity and the specific heat capacity of lightweight foamed concrete.

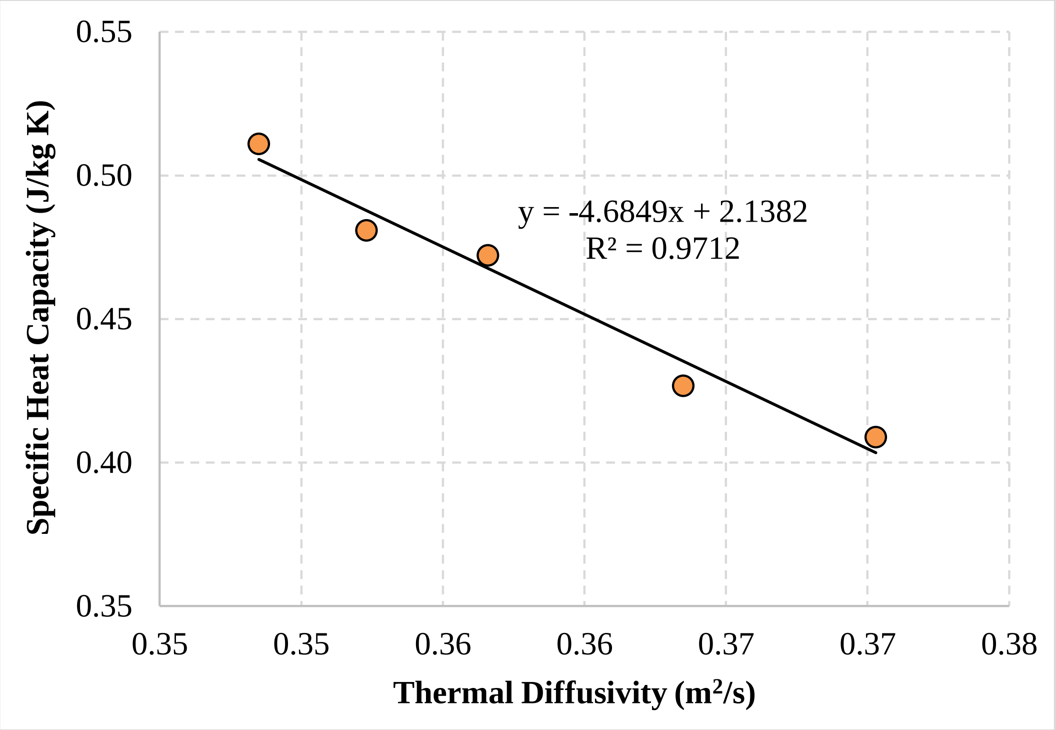

Fig. 12. Relationship between thermal conductivity and specific heat capacity of foamed concrete

5. Conclusion

In this experimental study, the durability and thermal properties of lightweight foamed concrete with the inclusion of different weight fractions of sugarcane fibre into lightweight foamed concrete were carried out. A density of 800kg/m^3 was prepared and tested, with five different weight fractions of SF added, which were 0.00%, 0.15%, 0.30%, 0.45% and 0.60%. The experimental results revealed that the best results, in terms of the durability properties (water absorption, porosity, drying shrinkage and ultrasonic pulse velocity) and thermal properties (thermal conductivity, thermal diffusivity and specific heat capacity) were accomplished with the optimum inclusion of 0.45% weight fraction of SF. At 0.45% weight fraction of SF, the fibres and the cementitious matrix achieved maximum compaction, which stemmed in good mix homogeneity. Beyond the optimum level of SF inclusion, agglomeration and the non-uniform dispersion of fibres was observed, which led to drop in entire durability and thermal properties evaluated.

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