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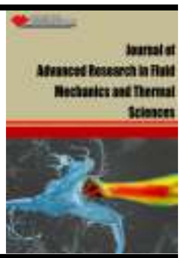

Influence of Mesocarp Fibre Inclusion on Thermal Properties of Foamed Concrete

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ABSTRACT

The addition of mesocarp fibre as a bio-composite material in foamed concrete can be well used in building components to provide energy efficiency in the buildings if the fibre could also offer excellent thermal properties to the foamed concrete. It has practical significance as making it a suitable material for building that can reduce heat gain through the envelope into the building thus improved the internal thermal comfort. Hence, the aim of the present study is to investigate the influence of different volume fractions of mesocarp fibre on thermal properties of foamed concrete. The mesocarp fibre was prepared with 10, 20, 30, 40, 50 and 60% by volume fraction and then incorporated into the 600, 1200 and 1800 kg/m^3 density of foamed concrete with constant cement-sand ratio of 1:1.5 and water-cement ratio of 0.45. Hot disk thermal constant analyser was used to attain the thermal conductivity, thermal diffusivity and specific heat capacity of foamed concrete of various volume fractions and densities. From the experimental results, it had shown that addition of mesocarp fibre of 10-40% by volume fraction resulting in low thermal conductivity and specific heat capacity and high the thermal diffusivity of foamed concrete with 600 and 1800 kg/m^3 density compared to the control mix while the optimum amount of mesocarp fibre only limit up to 30% by volume fraction for 1200 kg/m^3 density compared to control mix. The results demonstrated a very high correlation between thermal conductivity, thermal diffusivity and specific heat capacity which R^2 value more than 90%.

1. Introduction

The urgency of working towards a truly sustainable energy future has been more important as people become to appreciate the consequences of an increased risk of unpredictable, severe weather and rapid ecosystem changes caused by climate change that inextricably related to energy usage. To reduce energy consumption and increase energy efficiency in buildings, it is necessary to enhance the thermal properties of concrete, which are important to the use of this material as the primary building material to provide thermal insulation and fire resistance. Conventionally, thermal properties of concrete can be enhanced by simply incorporating air voids into concrete mixture by means of utilizing porous aggregates or by using aerated cement paste [1]. However, current

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understanding of concrete's thermal conductivity is still lacking thus more experimental studies are needed to investigate the impact of various factors on foamed concrete. Benmansour *et al.,* [2] found that the embedded natural fibre with sufficient amount directs to number of porosity and air in the matrix thus increases the insulating capacity of the concrete by decreasing its thermal conductivity. Then, thermal conductivity of the composites is also strongly influenced by water absorption [3]. As thermal conductivity is reported decreases with decreasing of the moisture absorbed due to hindered heat propagation, the volume fraction of mesocarp fibre may be another key factor that affecting the thermal properties of foamed concrete. Meanwhile, Asadi *et al*., [4] concluded in their study that density is the property with the best relation to the thermal conductivity of concrete. Hence, the mesocarp fibre was prepared with 10, 20, 30, 40, 50 and 60% by volume fraction and then incorporated into the 600, 1200 and 1800 kg/m^3 density of foamed concrete with constant cement-sand ratio of 1:1.5 and water-cement ratio of 0.45 for this study. The addition of mesocarp fibre as a bio-composite material in foamed concrete can be well used in building components to provide energy efficiency in the buildings if the fibre could also offer excellent thermal properties to the foamed concrete. It has practical significance as making it a suitable material for building that can reduce heat gain through the envelope into building thus improved the internal thermal stability [5]. In this paper, the effect of volume fraction of mesocarp fibre on the thermal conductivity, thermal diffusivity and specific heat capacity of foamed concrete with different density were studied. Then, the relationship of these parameters was presented using coefficient of determination (R^2) value.

2. Materials and Mix Design

2.1 Fine Sand

The local river sand was used as a fine aggregate for this study. The particles size smaller than 1.18 mm was sieved and dried according to the procedure used by Amran *et al.,* [6] found that the fine aggregate that smaller than 4mm was suitable to be used for foamed concrete to improve the flow characteristic and stability. Figure 1 demonstrates the fine aggregate grading curve utilized for this study. It has a fineness modulus of 1.35 as well as a specific gravity of 2.74. The sieved fine aggregates were than stored in a tank and ready to be used for mixing.

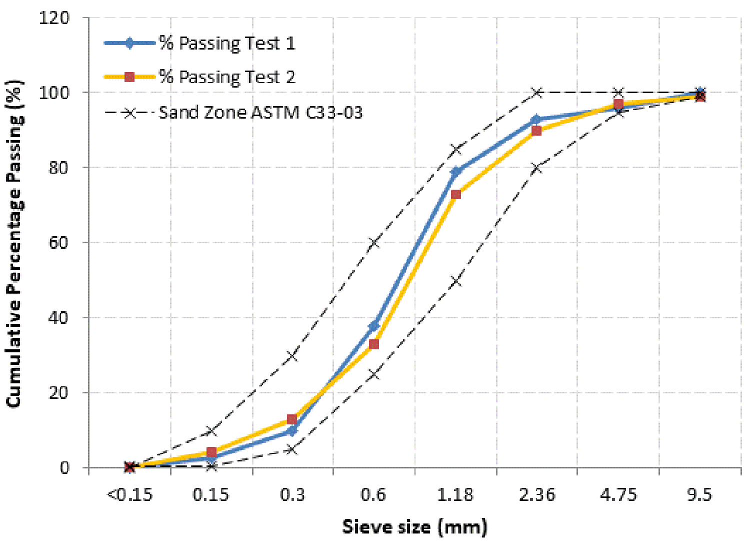

Fig. 1. Fine aggregate grading curve used for this investigation

2.2 CEM1 Cement

Ordinary Portland Cement (OPC) is a type of cement which certified to MS EN 197-1:2014 was used as the main binder material for this study. The product weighed 50 kilograms bags in bulk form. The chemical analysis properties of the ordinary Portland cement (OPC) used in this study are presented in Table 1

Table 1
The chemical properties of ordinary Portland cement

Bulk Oxide	Ordinary Portland Cement (% by mass)	Specification limit (ASTM)
SiO_2	16.00	20.00 min
Al_2O_3	3.90	6.0 max
Fe_2O_3	2.90	6.0 max
MgO	1.50	6.0 max
SO_3	3.10	3.0 max

2.3 Water

According to BS 3148: 1980, clean portable tap water was used for this study. It was an important agent to fulfil the most important function of the concrete mixing which allowed the binder content undergo hydration process. Apart from that, it is significant to note that the water used in the current research has a good and acceptable quality with suitable pH ranging from 6.5 to 8.0 and originated from Universiti Sains Malaysia, School of Housing, Building and Planning.

2.4 Stable Foam

Protein based surfactant (Noraite PA-1) was opted for this experimental study owing its characteristics of good quality, potent and dense cell bubble structure. The foaming agent was diluted with water to a ratio of 1:40 and then aerated to a density of 600, 1200 and 1800 kg/m^3. Portafoam PM 1 foam generator had been used to produce the stable foam. This foaming generator equipped with a digital timer that can set the flow rate acts a medium that transforms the liquid chemical into stable foam.

2.5 Mesocarp Fibre

Raw mesocarp fibre which collected from a local oil palm mill was used for this study. The mesocarp fibre has average length of 20mm as per shown in Figure 2. The fibre has been washed, soaked, rinsed in clean tap water to remove the excessive oil and sun-dried before using for the preparation of fibre reinforced foamed concrete. Table 2 visualizes the chemical and mechanical properties of mesocarp fibre used in this study.

Fig. 2. Mesocarp fibre used for this investigation

Table 2
Chemical and mechanical properties of mesocarp fibre

Lignin (%)	11
Cellulose (%)	60
Ash content (%)	3
Tensile strength (MPa)	78
Young's modulus (MPa)	495
Elongation at break (%)	17

2.6 Mix Design

The mixture was designed to achieve target dry density of 600, 1200 and 1800 kg/m^3. According to the previous research, the water-cement ratio was typically in the range of 0.4–0.8 depending on the mixture composition, consistency requirements, the use of chemical admixtures and the foam stability. In addition, the water-cement ratio should not be less than 0.35 before the introduction of the foam. It was because too little water in the mix might cause the cement to draw its moisture requirement from the foam, causing the latter to partly or fully collapses. Therefore, practical workability was attained by constant ratio of 0.45 and 1:1.5 of water-cement and cement-sand respectively. Besides, workability of fresh concrete reduced with increase in fibre content due to the characteristic water absorption of natural fibre. Thus, fibre with 10%, 20%, 30%, 40%, 50% and 60% by volume fraction of the total mix were selected to have a comparable study of volume fractions of fibre as composite materials in the foamed concrete thus its optimum percentage can be determined. The details for all mix designs are shown in Table 1.

Table 1
Details of mix design

Sample	CTRL	MF-10	MF-20	MF-30	MF-40	MF-50	MF-60
Water-cement ratio	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Cement-sand ratio	1:1.5	1:1.5	1:1.5	1:1.5	1:1.5	1:1.5	1:1.5
Target dry density (kg/m^3)	600	600	600	600	600	600	600
	1200	1200	1200	1200	1200	1200	1200
	1800	1800	1800	1800	1800	1800	1800
Mesocarp fibres (%)	0	10	20	30	40	50	60

3. Experimental Setup

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 (mm^2/s), specific heat capacity (MJ/m^3K) and thermal conductivity (W/mK) 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.

4. Results

4.1 Thermal Conductivity

Figure 3 summarized the results of thermal conductivity of foamed concrete with different volume fractions of mesocarp fibre of different densities. In general, thermal conductivity of lower density was expected to be lower compared to higher density of foamed concrete as the thermal conductivity reacts proportionally with a density [7]. It was because lower density of foamed concrete had larger porosity value compared to higher density foamed concrete and consequently lower the thermal conductivity [5]. Furthermore, this study had confirmed that by adding 10-30% of mesocarp fibre in 1200 kg/m^3 density and 10-40% of mesocarp fibre in both 600 and 1800 kg/m^3 density significantly decreased the thermal conductivity than control mix. These results corroborated the facts that the addition of mesocarp fibre could lead to formation of pores in concrete with larger size and wider distribution thus increased the insulating capacity of foamed concrete that reflect the previous study which indicated the increasing steel fibre addition in the concrete results higher thermal conductivity, neglecting that the increased fibre content in the concrete could increase the total porosity of the specimen and may resulting lower thermal conductivity values [8, 9].

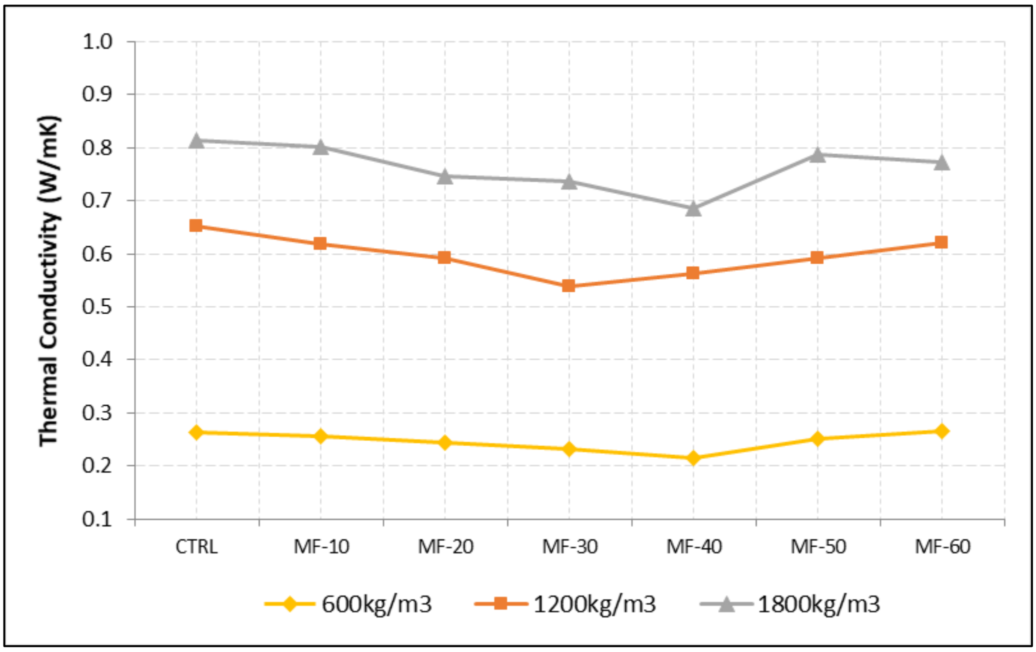

Fig. 3. Thermal conductivity of foamed concrete of different densities and volume fraction of mesocarp fibre

Therefore, the results had revealed by adding mesocarp fibre more than 30% in 1200 kg/m^3 density and 40% in both 600 and 1800 kg/m^3 density had increased the thermal conductivity to almost similar with control mix. This rather contradictory result might also be due to the location and relative orientation of the pores [10]. Pores that had generated by mesocarp fibres beyond this level was at right angle to the direction of heat flow which leading to more heat passing through the pores thus increased the thermal conductivity. The presence of high cellulose content (60%), the mesocarp fibre will instantly absorb water and have excellent wettability to enhance the composite's performance with foamed concrete [11]. These results in agreement with Xie *et al.,* [12] who found that more thermal resistance was observed if a layer of pores was parallel to the direction of heat flow.

4.2 Thermal Diffusivity

As well as thermal conductivity, thermal diffusivity of lower density was expected to be lower compared to higher density of foamed concrete and it was important to note that the addition of mesocarp fibre had also significantly affect the thermal diffusivity. For example, the results demonstrated that the value of thermal diffusivity keep increasing by adding mesocarp fibre and the maximum value was obtained at 30% and 40% for 1200 and both 600 and 1800 kg/m^3 density respectively. These findings indicated that the fibre was effective at diffusing the heat energy with the optimum volume fraction.

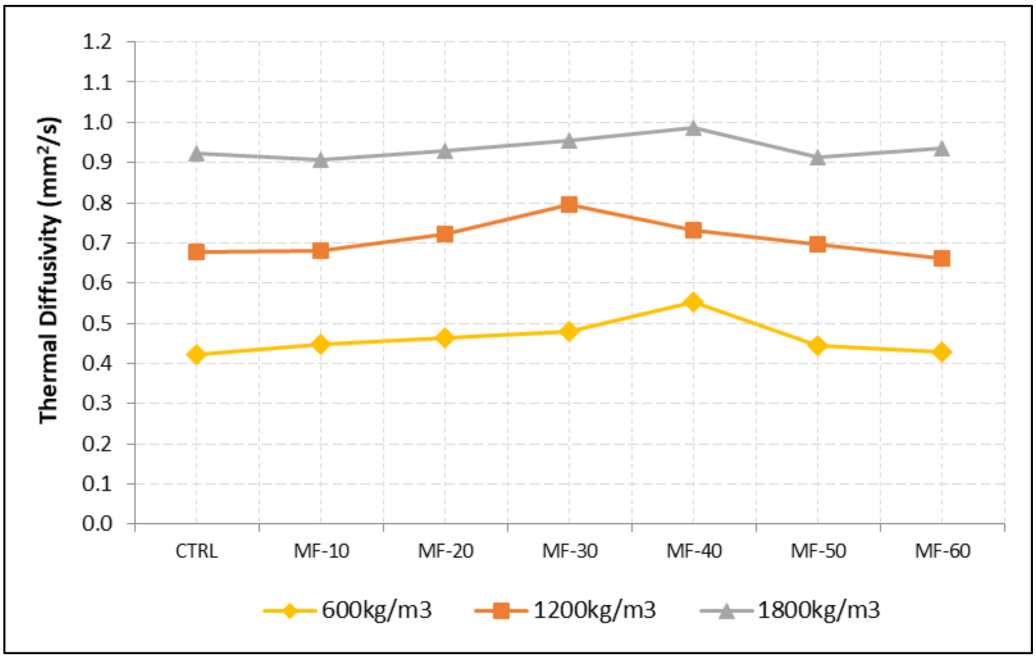

Fig. 4. Thermal diffusivity of foamed concrete of difference densities and volume fraction of mesocarp fibre

When relate to the previous findings on thermal conductivity, we can infer that air was effective at diffusing the energy while could only absorb a relatively small amount of thermal energy [13]. The increase in thermal diffusivity caused by the existence of the mesocarp fibre could be attributed to the porosity explained that not all capillary pores and entrained air voids were taking part in water absorption if they were not interconnected [14]. As a result, higher thermal diffusivity still can be achieved compared to the control mix. By contrast, addition of mesocarp fibre that exceed its optimum volume fraction such as 60% for all densities did not seem to notably improve the thermal diffusivity than control mix. This was due to the excessive fibre in the foamed encouraged the formation of interconnected pores thus leading to high water absorption and density thereby lower the thermal diffusivity. Indeed, the thermal diffusivity of water is much lower than air due to its molecular structure [15]. This finding was consistent with other study which mentioned that higher moisture absorption in concrete matrix occurs due to the nature of natural fibres which has higher cellulose content [16].

4.3 Specific Heat

Figure 5 showed that foamed concrete with 10-30% of mesocarp fibre in 1200 kg/m^3 density was expected to continue decreasing the specific heat capacity compared to the control mix. Meanwhile, the specific heat capacity for both 600 and 1800 kg/m^3 density could be reduced with 10-40% of mesocarp fibre than control mix. Compared to the control mix, the lowest value of specific heat capacity was achieved by adding 30% of mesocarp fibre for 1200 kg/m^3 density and 40% of mesocarp fibre for both 600 and 1800 kg/m^3 density. On the other hand, the addition of mesocarp fibre more than that volume fractions would dramatically decrease its effectiveness in lowering the specific heat capacity of foamed concrete. For example, 50-60% of mesocarp fibre was notably not affect the specific heat capacity compared to control mix of any densities.

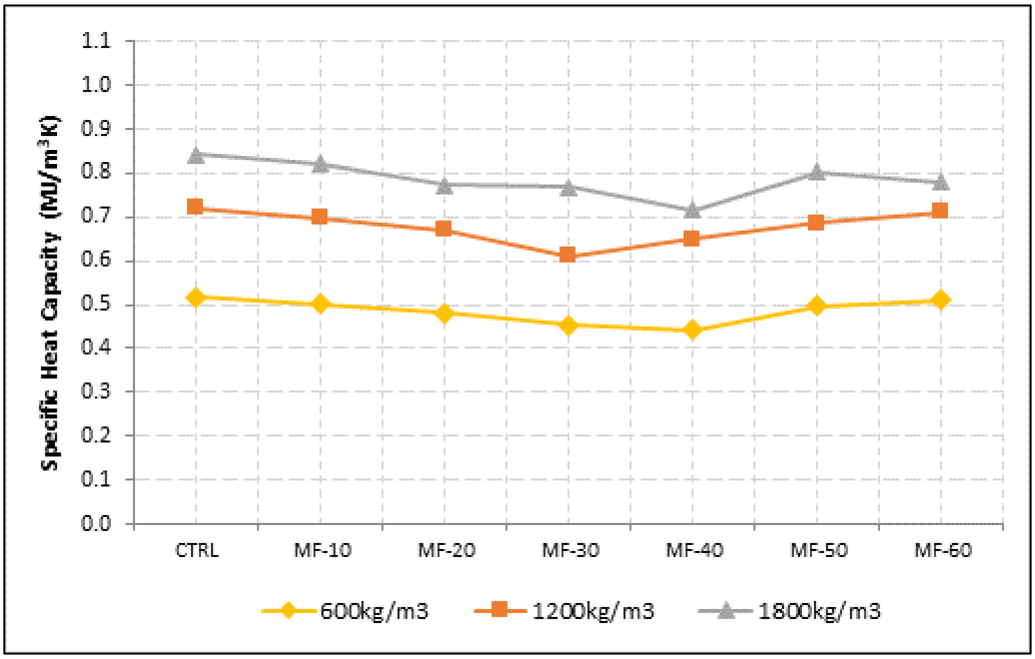

Fig. 5. Specific heat capacity of foamed concrete of difference densities and volume fraction of mesocarp fibre

It can therefore be assumed that the incorporation of sufficient amount of mesocarp fibre in foamed concrete was excellent at reducing the heat gain. A possible explanation for this might be attributed to the partially loss of mass due to degradation of material that initiated the microchannels for releasing of vapours [17]. As pores in foamed concrete would fill with hydration products, the amount of heat absorbed is less for dehydration of chemically bound water thus its specific heat capacity is reduced [18].

4.4 Relationship between Thermal Diffusivity and Thermal Conductivity

The relationship between thermal diffusivity and thermal conductivity was illustrated in Figure 6 as increase in thermal diffusivity lessens the thermal conductivity. There was a very strong negative correlation between thermal diffusivity and thermal conductivity for 1800 kg/m^3 density of foamed concrete with 0.9453 of coefficient of determination (R^2) followed with 1200 kg/m^3 and 600 kg/m^3 density of foamed concrete with coefficient of determination (R^2) of 0.9194 and 0.9144 respectively.

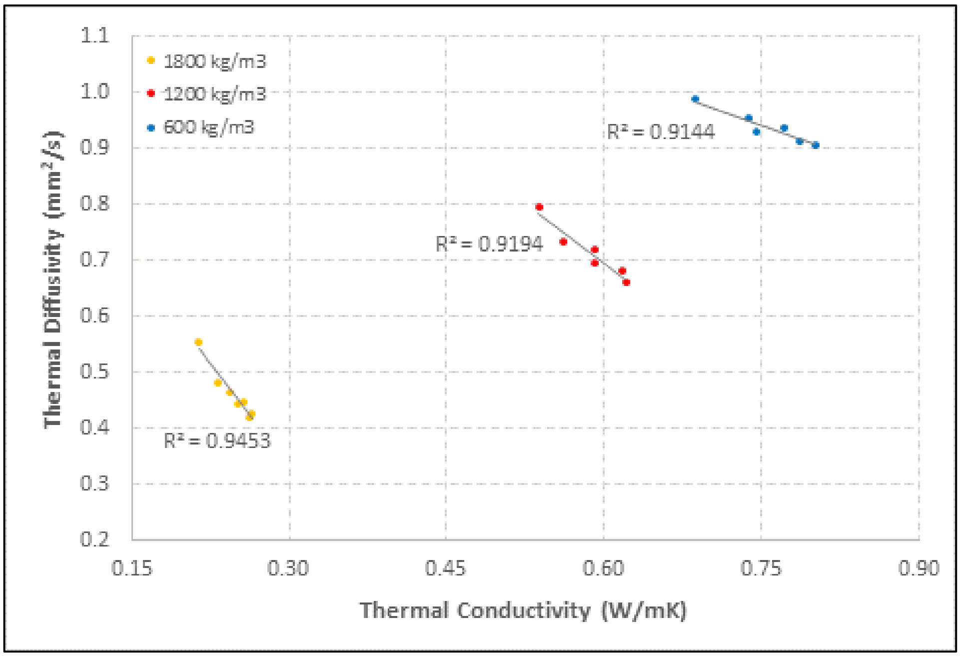

Fig. 6. Relationship between thermal diffusivity and thermal conductivity of difference densities

4.5 Relationship between Specific Heat Capacity and Thermal Conductivity

Figure 7 shows the specific heat certainly influenced the thermal conductivity as the specific heat capacity decrease, the thermal conductivity decreases and vice versa. There was a very strong correlation between specific heat capacity and thermal conductivity for 600 kg/m^3 density of foamed concrete with 0.9701 of coefficient of determination (R^2) followed with 1800 kg/m^3 and 1200 kg/m^3 density of foamed concrete with coefficient of determination (R^2) of 0.9589 and 0.9571 respectively.

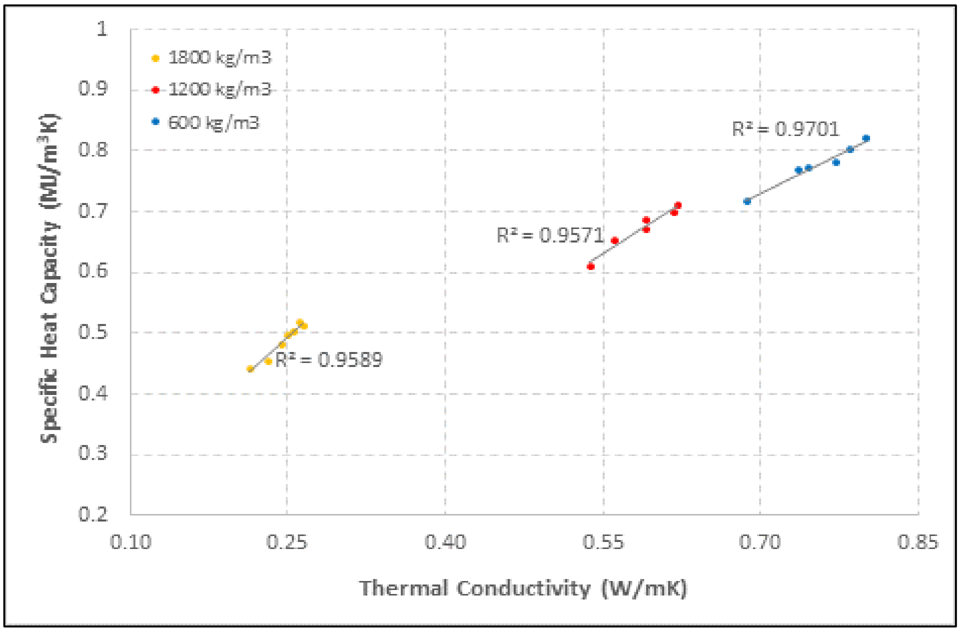

Fig. 7. Relationship between specific heat capacity and thermal conductivity of difference densities

4.6 Relationship between Thermal Diffusivity and Specific Heat Capacity

The relationship between thermal diffusivity and specific heat capacity is shown in Figure 8. Based on the data, the thermal diffusivity increased as the specific heat capacity decreased. There was a very strong negative correlation between thermal diffusivity and specific heat capacity for 1200 kg/m^3 density of foamed concrete with 0.9902 of coefficient of determination (R^2) followed with 1800 kg/m^3 and 600 kg/m^3 density of foamed concrete with coefficient of determination (R^2) of 0.9527 and 0.9034 respectively.

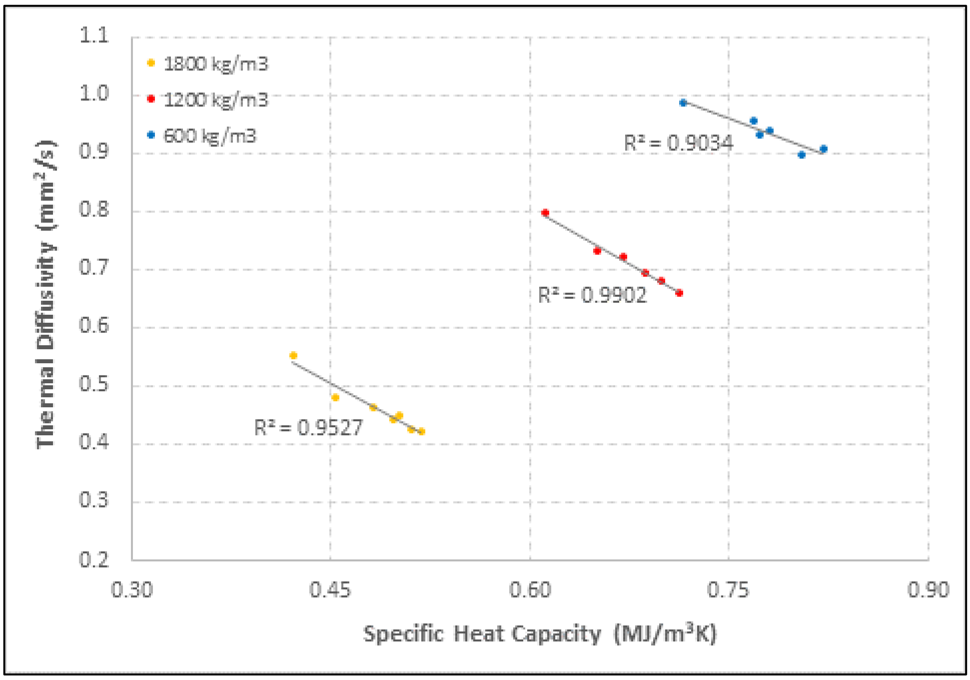

Fig. 8. Relationship between thermal diffusivity and specific heat capacity of difference densities

5. Conclusions

The incorporation of 10-30% of mesocarp fibre by volume fraction in 1200 kg/m^3 density foamed concrete showed a progressively change of thermal properties such as lower thermal conductivity and specific heat capacity and higher thermal diffusivity compared to the control mix. On the other hand, 10-40% of mesocarp fibre by volume fraction in 600 and 1800 kg/m^3 density foamed concrete also showed a dramatically change of thermal properties such as lower conductivity and specific heat capacity and higher thermal diffusivity compared to the control mix. Based on the experimental data, the increase thermal diffusivity decreases the thermal conductivity, the decrease specific heat capacity decreases thermal conductivity and the increase thermal diffusivity decreases specific heat capacity. The results demonstrate a very high correlation between thermal diffusivity and thermal conductivity, specific heat capacity and thermal conductivity and thermal diffusivity and specific heat capacity which R^2 value more than 90%.

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