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Thermal Properties of Foamed Concrete with Addition of Empty Fruit Bunch (EFB) Fiber

M.Musa, M.A. Othuman Mydin, A.N. Abdul Ghani

Abstract: ***The key players in the construction industry around the globe are very enthusiastic in producing better construction materials that are cost-effective, durable, excellent thermal insulation, lightweight and long lasting without jeopardizing the environment. One of the best ways in producing such building materials are by incorporating industrial waste materials such as Empty Fruit Bunch (EFB) fiber in foamed concrete (FC). In recent years, the spotlight has been given towards the use of natural fiber reinforced concrete-based materials especially in Malaysia in a quest of economic and environmental upkeep particularly in the construction sector itself. Hence, this study intended to recognize the influence of Empty Fruit Bunch (EFB) fiber of four different contents (0.15%, 0.30%, 0.45% and 0.60 %) by mix volume on thermal properties of FC. There were three densities of 800kg/m³, 1100kg/m³ and 1400kg/m³ we cast and tested. The mix design of FC (sand: cement: water) is fixed at the ratio of 1:1.5:0.45. The investigation focuses on three parameters which were thermal conductivity, thermal diffusivity and specific heat capacity. Results showed that the addition of EFB in FC plays an important role to improve the thermal performance holistically. The results demonstrated a great potential possesses by the EFB fiber to be utilized in cement-based materials such as the FC mix which is beneficial in reducing the thermal property or the transfer of heat in a produced concrete.***

Keywords: ***Thermal conductivity, diffusivity, specific heat capacity, foamed concrete, concrete, mortar***

I.INTRODUCTION

Currently, the attention on natural fiber reinforced concrete based materials could be seen increasingly rising in Malaysia in the quest for economic and environmental importance in the construction sector and built environment. There are numerous types natural fibers utilized broadly in industries for making Foamed Concrete (FC). The main reason for adding the natural fibers in FC is to augment the physical and mechanical performances.

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*****Correspondence Author(s)
M.Musa, School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia.
M.A. Othuman Mydin, School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia.
A.N. Abdul Ghani, School of Housing, Building and Planning, Universiti Sains Malaysia, 11800, Penang, Malaysia.

The natural fibers can play an important role in improving the bonding between the cement matrix which will increase the bending strength as well as the structural integrity of FC [1]. Palm oil production is significant for the Malaysian economy, which is the world's second-largest producer of the product behind Indonesia. It should be pointed out that the Malaysian palm oil industry produces approximately 17.7 million tons of palm oil from a planted area of 4.5 million hectares [2]. Throughout the world, there are roughly 417 productive palm oil extraction mills [3] and about 22.5 million tons of empty fruit bunch (EFB) solid waste produced by these plants annually. During the production of palm oil, a substantial quantity of solid waste are generated in the form of fibers which are from the fronds, empty fruit bunches, palm tree trunk, and kernel shells. These natural fiber wastes are usually merely disposed of without getting any economic return. Hence, this study will investigate the influence of EFB fiber inclusion on thermal properties of FC due to it being a beneficial and environmentally friendly material compared to conventional concrete.

II.LITERATURE REVIEW

2.1 Foamed Concrete (FC)

FC is normally produced using the blending of slurry mortars to stable froth. It encased small air rises inside the mortar that can be coming to as the totals in this manner making it lighter and having special properties, for example, low thermal conductivity and high imperviousness to fire. Controlling the quality of the foam result in foamed concrete with densities running from as low as 500kg/m³ to 1600kg/m³. Because of its restricted utilisation of totals because of the nonattendance of coarse totals and high limit in consolidating waste materials, foam concrete can be viewed as an environmentally friendly material [4]. FC is great in handling pressure, however it is extremely weak to strain and will in general be delicate. The addition of fiber into FC is a way to upgrade its engineering properties and additionally can improve the thermal properties. FC differentiates itself from other air filled materials by having air content upwards of 25% compared to its volume. However, in some cases the air cells created by the foam account for 80% of its volume [5].

FC is frequently utilized in construction as intermediary structures in the provision of porous thermally insulating materials or lightweight components. Coarse aggregates are absent from FC, making it a more lightweight material.

The condensed density also aids in decreasing its self-weight. Air bubbles are introduced in the form of a foaming agent during the FC mixing process. This produces air voids in its matrix, resulting in a porous structure while producing micro-porous which diminish the interfacial bonding and have a strong plasticizing effect on the FC. There are various types of FC produced in a wide range of densities for non-structural and structural applications. The classification of FC can be based on how it's cured, the binder type used, or the method used in creating its microstructure (pores). Addition to the density of the aggregates, the density of the mortar also depends on the grading of the aggregates, the mix proportions, moisture content, chemical and mineral admixtures and also the binder ratio [6].

FC with a density of less than 800kg/m³ is used for non-structural applications such as acoustic insulation, sub-base fill, thermal insulation, firewalls and underground thermal conduit linings. FC with density above 800kg/m³ is used for roofs and floors [7]. FC reduces a structure's dead weight and as a consequence this aids in simplifying the plans of supporting structures including the footing and walls of lower levels. FC is also acknowledged as an environmentally friendly building element. This is due to its low usage of natural resources by the elimination of coarse aggregates for example, and also the use of waste products such as rice husk or fly ash whenever possible [8].

2.2 Thermal Conductivity

Heat conductivity is critical in building insulation, material science and related fields especially where high operating temperatures are experienced. Thermal conductivity is also known as the property of material that shows the ability to conduct heat. Previous studies show that FC provides better thermal insulation properties and have a higher potential to be used as an environmental material in the construction industry especially in hot weather countries like Malaysia [9]. FC possesses excellent thermal insulation properties due to it pore structure that have content in it. Thermal conductivity *k*, is the amount of heat that passes through homogenous materials with thickness 10mm to 20mm and diameter of specimen is more than 30mm with the quantity of heat will flow through unit area in unit time when difference unit of temperature exists between the faces of unit thickness of materials [10].

Thermal conductivity of FC with a density of 1000kg/m^3 is about one-sixth the value of typical cement sand mortar. Thermal conductivity of FC is 5 to 30% of that measured on standard weight concrete [11]. The range of thermal conductivity for dry densities values of 600-1600 kg/m^3 is between 0.1 and 0.7 W/mK and it will reduce with decreasing densities. Besides, moisture contents in concrete also another variable significantly influencing the thermal conductivity. This is because water has conductivity about 25 times more than air. Moreover, thermal conductivity is also higher when the air in the pores has been partially replaced by water or moisture [12].

2.3 Thermal diffusivity

Thermal diffusivity is defined as the ratio of the time derivative of temperature to its curvature, calculating the rate at which temperature concavity is evened out. Thermal diffusivity is how thermal inertia is valuated. Heat moves quickly through materials with high thermal diffusivity because they conduct heat faster relative to their volumetric heat capacity. Serri*et al.* [13] carried out a study to find out the influence of artificial lightweight aggregates on the thermal diffusivity of FC. They found that the degree of thermal diffusivity of FC reduces when the percentage of lightweight aggregate increases in the mix. The lowest rate was three times than the rate recorded for control FC samples with 0.31mm^2/s for LWAC17 as per shown in Fig. 1. Low thermal diffusivity occurs because of the compatibility in comparative stiffness between the FC matrix and the artificial lightweight aggregate due to the shape of aggregate which is spherical and easy to be mixed in FC.

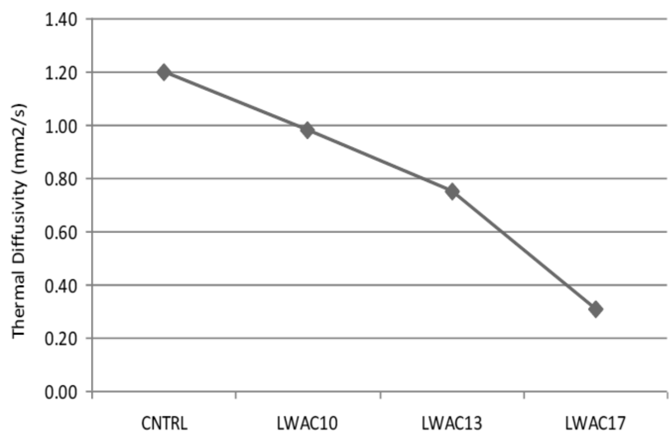

Fig. 1 Influence of artificial lightweight aggregate on thermal diffusivity of FC [13]

2.4 Specific Heat Capacity

Specific heat is the amount of the heat per unit mass that is needed to increase the temperature by one degree Celsius. The connection between heat and temperature change is normally written in the form where *C* is the specific heat. The connection does not apply if a phase change is present; this is because the heat lost or gained during a phase change does not affect the temperature. However, the specific heat test depends on the densities of specimen, values of thermal conductivity and thermal diffusivity. In the research conducted by Serri *et al.* [13] to scrutinize the effect of artificial lightweight aggregate on the thermal diffusivity of FC, he concluded that the specific heat capacity of FC increased when the percentage of lightweight aggregate increased in the mix as can be seen in Fig. 2.

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This was due to the water content and air pockets in the artificial lightweight aggregate. It should be pointed out that artificial lightweight aggregate has a very high water absorption capacity because its raw material is silt which tends to absorb water very quickly. This will escalate the requisite amount of energy to increase a unit mass of material by one unit of temperature at a constant pressure. Specific heat capacity is also contingent on the distribution of lightweight aggregates in the FC samples [14].

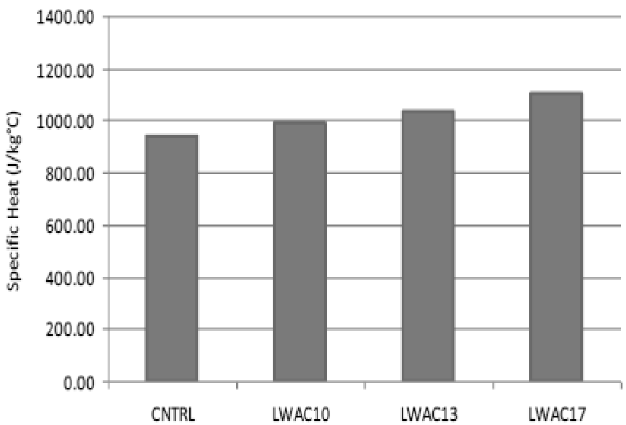

Fig. 2 Influence of artificial lightweight aggregate on thermal diffusivity of FC [13]

III.CONSTITUENT MATERIALS AND MIX DESIGN

3.1 Cement

Cement paste is the binder in FC that binds the fine aggregates together and reacts with mineral elements in the hardened body. The properties of FC depend on the amount and the quality of its constituents. This is due to cement being the most reactive constituent and its proper use is important in obtaining the desired properties of FC mixture. In this research, Ordinary Portland Cement (OPC) made by YTL Cement SdnBhd was used from start to finish. The OPC or ASTM Type 1 which complies with BS EN 12 was used as the main binder.

3.2 Fine Aggregate

Fine aggregate is an aggregate that contains a majority of particles going through a 4.75mm sieve and mostly held at 75µm. Sieve analysis of fine aggregate is to acquire its grading, gravity and water absorption. For this research, locally sourced river sand was used in which the fine sand was oven dried for 24 hours at 110°C in order to eliminate its water content. The sand was filtered through a sieve of 2.36mm after being oven dried. Table 1 shows the characteristics of fine sand used in this research.

Table. 1 Characteristics of fine aggregate

Component	Value
True density (γ_0)	2645–2705 kg/m^3
Bulk density (γ_{bulk})	1530–1585 kg/m^3
Silt and clay particles	2.42%
Fineness modulus	0.88-1.21
Organic inclusions	nil
Water absorption	1.14%

3.3 Water

Water is one of the most vital components in fabricating FC. The first purpose is to enable the binder content to undergo a hydration process of cement and durability to form hardened concrete. Second, water will ensure the binder content mixes with the aggregate to create a workable mixture. In this research, tap water was used to cast FC, the tap water was clean and potable. The water-cement proportion was kept steady all through this study, which is 0.45. This proportion has been picked on the grounds that it demonstrated attractive usefulness.

3.4 Foaming agent

Foam is a form of stable froth, made by mixing foaming agent and water in a foam generator. Its purpose is to guide the density of FC by incorporating dry preformed stable foam into fresh FC. The research used a protein based surfactant (Noraite PA-1). The proportion of foaming agent to water is 1:30 by volume. The foam density is 60-70kg/m³, in this study the foam density used is 65kg/m³. The foaming generator (Portafoam TM2 machine) is used in order to generate the foam agent to transfer the protein into foam. The density of FC was controlled by the volume of foam included for certain mixes. Fig. 3 shows the production of stable foam through the Portafoam TM2 machine.

Fig. 3 Production of stable foam through Portafoam TM2 machine

3.5 Oil Palm Empty Fruit Bunch (EFB) Fiber

EFB fibers are not commonly used in the construction industry but are often discarded as waste. EFB fibers are available in large quantities in Malaysia. This is because the EFBs are part of all oil palm waste thrown away by oil palm factories.

With the advantages of high nutrient content in EFB, it is now utilised as a nutrient and a mulch source in the field. Besides, another advantage of using EFB is its non-polluting character. Initially, due to a high pH of 5 and a high potassium content of about 26%-32% EFBs were used as bunch ash. However, during the ashing process most of the nutrient content like organics and nitrogen were lost, so the utilisation as bunch ash is no longer implemented.

Moreover, empty fruit bunches (EFB) are also used as industry material for the production of chemical substances such as furfural and ethanol, pulp and paper, and compact fuel. As demand for EFB in oil palm plantations has gone up, it is necessary to use EFBs more effectively. Therefore, this research will investigate the effect of oil palm empty fruit bunches (EFB) fiber usage on durability, thermal and mechanical properties of FC due to the beneficial and environmentally friendly material compared to conventional concrete.

In this study, the size for the empty fruit bunch (EFB) was 19mm with different volume fractions of 0.15%, 0.30%, 0.45% and 0.60% (Fig. 4). The samples were cured using moisture curing and being left under exposure for 7, 28, 60 and 180 days. Table 2 displays its physical properties and Table 3 shows the chemical compositions of EFB fiber used for this research.

Fig. 4 Empty Fruit Bunch (EFB) fiber used in this study

Table. 2 Physical properties of EFB fiber used for this study

Component	Value
Length (mm)	19
Density (g/cc)	1.43
Elongation at break (%)	9.73%
Tensile strength (N/mm^2)	195
Tensile modulus (GPa)	6.45
Runkel ratio	0.55
Area of fiber (μm^2)	75.58
Diameter of fiber (µm)	12.45
Diameter of lumen (µm)	7.86

Table. 3 Chemical composition of EFB fiber used for this study

Component	Percentage
Lignin	24.90%
Cellulose	47.90%
Hemi-Cellulose	17.10%
Extractives	2.60%
Ash Content	5.40%
Water Soluble	2.10%

3.6 Mix Design

The mix design of FC consist of Type-1 Ordinary Portland Cement, sand, water, protein agent also known as foam and oil palm empty fruit bunches (EFB) fiber. The ratio for cement, sand and water was maintained at 1:1.5:0.45. The size of the empty fruit bunches (EFB) fiber was 19mm with different volume fractions of 0.15%, 0.30%, 0.45% and 0.60%. A mix design of FC will be tested in selected densities of $800kg/m^3$, $1100kg/m^3$ and $1400kg/m^3$. The ratio of foaming agent to water is 1:30 by volume. There were a total of 15 blends set up for this research. The mix design proportions for $800kg/m^{3,}$ $1000kg/m^3$ and $1400kg/m^3$ are shown in Table 4. The samples were cured by moisture curing. The sieve maximum grain size for this research is 2.36mm, and the slump values between 22cm to 25cm.

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Table. 4 Design mix proportions

Sample Reference	Mix Density (kg/m^3)	Cement (kg)	Fine Aggregates (kg)	EFB Content (kg)	Water (kg)
Control-800	800	15.12	22.68	-	6.81
0.15% EFB-800	800	15.12	22.68	6.69	6.81
0.30% EFB-800	800	15.12	22.68	13.38	6.81
0.45% EFB-800	800	15.12	22.68	20.00	6.81
0.60% EFB-800	800	15.12	22.68	26.76	6.81
Control-1100	1100	20.54	30.81	-	9.24
0.15% EFB-1100	1100	20.54	30.81	9.08	9.24
0.30% EFB-1100	1100	20.54	30.81	18.17	9.24
0.45% EFB-1100	1100	20.54	30.81	27.26	9.24
0.60% EFB-1100	1100	20.54	30.81	36.35	9.24
Control-1400	1400	25.96	38.93	-	11.68
0.15% EFB-1400	1400	25.96	38.93	11.48	11.68
0.30% EFB-1400	1400	25.96	38.93	22.97	11.68
0.45% EFB-1400	1400	25.96	38.93	34.45	11.68
0.60% EFB-1400	1400	25.96	38.93	45.94	11.68

IV.EXPERIMENTAL SETUP

Generally, thermal conductivity measures the ability of the material to conduct heat, which is defined as the rate of the flux of heat of temperature gradient. There are a lot of factors that can affect the thermal conductivity of foam concrete such as its density, moisture content and constituents of the material. As thermal conductivity is hugely influenced by density, the product does not need to be moist cured of autoclaved. The amount of pores also contributed to thermal insulation. Finer pores make for better insulation.

Thermal conductivity, k, is amount of heat that passes through homogenous materials of 10mm to 20mm thickness, with a diameter of 40mm and the quantity of heat that will flow through unit time when a difference in units of temperature exists between the faces of unit thickness of materials. Thermal conductivity is known as the property of material that shows its ability to conduct heat. The thermal conductivity test has been done on FC with oil palm empty fruit bunches (EFB) as a fiber. Thermal diffusivity and specific heat were recorded together.

The test examination on thermal properties secured three fundamental parameters which are thermal conductivity (W/Mk), specific heat (MJ/m^3K) and thermal diffusivity (mm^2/s). In this test, the example utilized is a square with a measurement of 5mm thickness example which was cored from a cube. The cored specimens were then put into ventilated ovens at 105Cº + 2Cº ±24 hours to guarantee the specimens were completely dry.

For setting up the specimen the methods are according to ASTM C332. The thermal properties of specimens at room temperature of 27ºC ± 2°C were estimated utilizing a Hot-Circle test TPS2500. In this study, a 6.403 diameter size of hot circle sensor was employed with output of power 0.12W and estimated time of 20 seconds. The sensor was set between two samples to decide the thermal conductivity. Estimation, examining profundity, power and time should have been set precisely by permitting the acknowledged rate before the test. The thermal diffusivity (mm^2/s) and specific heat (J/kg°C) were recorded together with thermal conductivity (W/mK) during the test. Materials of permeable attributes must be well taken into consideration and need more steps to think about their warming properties. In this study, vital qualities, for example, thermal conductivity, thermal diffusivity and specific heat were used to explore the thermal properties of the FC specimens. Fig. 5 demonstrates the set-up for a thermal properties test.

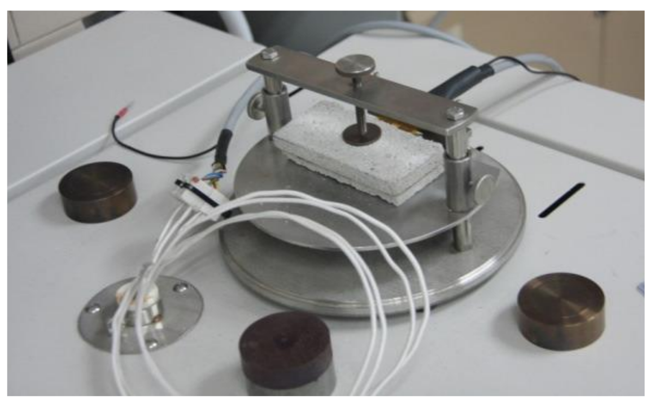

Fig. 5 Set-up for thermal test

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V.RESULT AND DISCUSSIONS

This part demonstrates the experimental findings and discussion of the properties of thermal namely the thermal diffusivity, specific heat capacity and FC thermal conductivity that is strengthened with different volume fraction of EFB fiber.

5.1 Thermal Conductivity

Thermal conductivity can be defined as a measurement of the heat flow which creating a temperature difference in a material. A precise thermal conductivity measurement can be attained at a steady-state conditions providing the heat flux and temperature are constant in time. The requirement of time and inherent difficulty to make accurate measurements has driven the development of transient techniques in the property measurement. Table 5 shows the thermal conductivity of FC mixes and Fig. 6 visualizes the thermal conductivity of FC with different EFB fiber volume fraction. From Table 4 and Fig. 6, it is clearly shown that the thermal conductivity of all FC strengthened with EFB fiber is certainly proportionate with its density. For example, the thermal conductivity for control FC (no fiber) reduced from 0.77 to 0.56W/mK and further reduced to 0.33W/mK for corresponding densities of 1400, 1100 and 800 kg/m^3 correspondingly. The results have confirmed that lower density of FC converts to lower thermal conductivity which is comparable to the findings from other researchers [15]. It should be noted that the density of FC is controlled by its porosity. The FC with higher density tend to have smaller porosity value as compared to lower density which affect the thermal conductivity of FC as a whole. In addition, the thermal conductivity could also be reduced if the volume of foam in the FC mix increases. The improvement of thermal conductivity of FC is the result of the air cavities expansion inside the mix which also considered as a bad conductor as compared to liquid and solid state due to its molecular structure. The increment of closed cavities enhancing the capability of good heat insulation in forming multi-cellular structures that exist in the FC mix.

The inclusion of EFB fiber in FC also had an impact on the thermal conductivity. For instance, for 1400 kg/m^3 density, the control FC (no fiber) achieved 0.77 W/mK while when the FC was strengthened with EFB fiber, it was observed that the conductivity value improved. Whereby for control specimen, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber exhibited 5%, 6% and 17% reductions in the heat flow respectively.

EFB fiber contains a high percentage of hemicellulose and lignin since it is a natural biodegradable product which helps in obtaining high heat resistant. Additionally, it also has a capability in storing more heat energy since it possesses a uniform formation of pore inside the FC mix. Low thermal conductivity can be obtained by inducing small and uniform pores by shrinking and swelling of EFB fiber in FC during the process of drying and mixing. Hence, the thermal conductivity will decrease when more EFB fiber are added. However, the sample with 0.60% EFB fiber for 1400 kg/m^3 density showed higher thermal conductivity compared to 0.45% EFB fiber. This may be due to non-uniform distribution of EFB fiber in FC once it achieved optimum volume fraction (0.45%).

Same improvement pattern can be observed for the remaining two densities. The thermal conductivities of FC of 800 kg/m^3 and 1100 kg/m^3 densities improved consistently with addition of EFB fiber up to the optimum percentage. For 800 kg/m^3 density, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber exhibited 6%, 30% and 3% reductions in the heat flow correspondingly compared to control FC specimen. While for 1100 kg/m^3 density, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber exhibited 7%, 11% and 20% reductions in the heat flow respectively in comparison to control FC specimen.

Apparently, the thermal conductivity values of produced FC reinforced with EFB fiber improved with increasing volume fractions of EFB fiber (until it reach optimum volume fraction), and their thermal conductivities were lower than that of the mortar by about 3–30% for 800 kg/m^3 density, 7-20% for 1100 kg/m^3 density and 5-17% for 1400 kg/m^3 density.

The results demonstrated that the EFB fiber has a great potential to be utilized in cement based material like FC in which it can play an important role to reduce the thermal inducing property or heat transfer of produced concrete. In addition, the produced FC from EFB fiber 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 FC and help to lessen energy consumption from room temperature tuning [15].

Table . 5 Thermal conductivity of FC mixes

Mix	Density		
	800 kg/m^3	1100 kg/m^3	1400 kg/m^3
Control (no fiber)	0.33 W/mK	0.56 W/mK	0.77 W/mK
0.15% EFB	0.31 W/mK	0.52 W/mK	0.73 W/mK
0.30% EFB	0.23 W/mK	0.50 W/mK	0.72 W/mK
0.45% EFB	0.32 W/mK	0.45 W/mK	0.64 W/mK
0.60% EFB	0.37 W/mK	0.54 W/mK	0.72 W/mK

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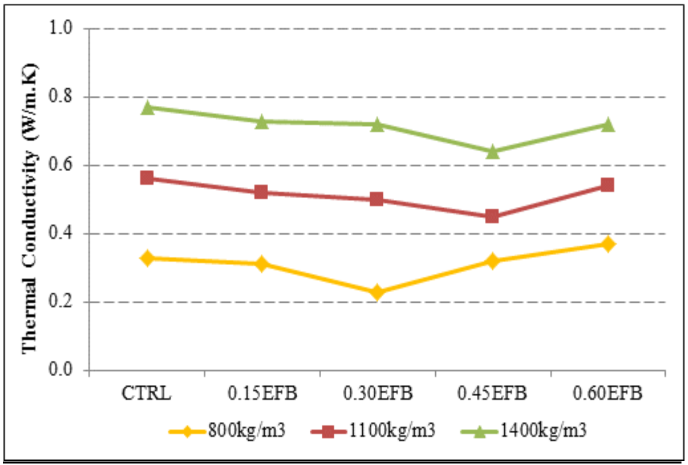

Fig. 6 Thermal conductivity of FC with different EFB fiber volume fraction

5.2 Thermal Diffusivity

Thermal diffusivity can be used to measure a material's transient thermal response with respect to the temperature changes. Concrete based materials that contain higher level of thermal diffusivity are said to possess an excellent thermal energy diffuser, whereby materials would experience a much slower thermal energy diffuser if they have a lower thermal diffusivity. In the case of there is a disparity within the thermal environment of the material, it is important to let the heat to flow in or out around the material what is called as thermal equilibrium is achieved. As a matter of fact, concrete based materials would achieve thermal equilibrium much quicker if they have higher thermal diffusivity as compared to materials containing low thermal diffusivity.

Thermal diffusivity will vary depend on different factors and influences since it is a function of density, specific heat and conductivity. For example, both specific heat and conductivity would increase in a moisturize condition and thus reducing the influence on diffusivity. Therefore, thermal diffusivity of FC is principally influenced by the mineralogical characteristics of the mix design. Table 6 shows the thermal diffusivity of FC mixes and Fig. 7 demonstrates the thermal diffusivity of FC with different EFB fiber volume fraction.

Table. 6 Thermal diffusivity of FC mixes

Mix	Density		
	800 kg/m^3	1100 kg/m^3	1400 kg/m^3
Control (no fiber)	0.48 mm^2/s	0.61 mm^2/s	0.71 mm^2/s
0.15% EFB	0.44 mm^2/s	0.56 mm^2/s	0.67 mm^2/s
0.30% EFB	0.32 mm^2/s	0.54 mm^2/s	0.65 mm^2/s
0.45% EFB	0.45 mm^2/s	0.48 mm^2/s	0.57 mm^2/s
0.60% EFB	0.53 mm^2/s	0.59 mm^2/s	0.65 mm^2/s

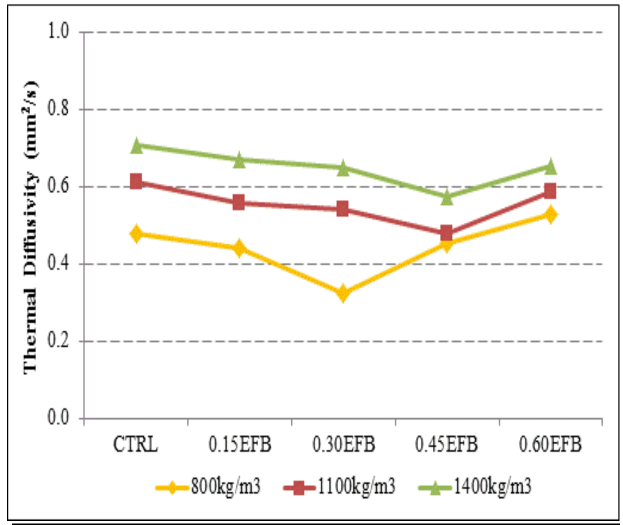

Fig. 7 Thermal diffusivity of FC with different EFB fiber volume fraction

Table 6 and Fig. 7 reveal that the addition of EFB fiber in FC also had an impact on the thermal conductivity. For example, for 1400 kg/m^3 density, the control FC (no fiber) achieved 0.71 mm^2/s while when the FC was strengthened with EFB fiber, it was observed that the thermal diffusivity value reduced gradually. Compared to control specimen, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber exhibited 6%, 8% and 20% reductions in the thermal diffusivity in that order. Same pattern can be perceived for the remaining two densities. The thermal diffusivities of FC of 800 kg/m^3 and 1100 kg/m^3 densities reduced constantly with inclusion of EFB fiber up to the optimum percentage. For 800 kg/m^3 density, FC strengthened with 0.15% EFB fiber and 0.30% EFB fiber exhibited 8% and 33% reductions in the thermal diffusivity respectively compared to control FC specimen. While for 1100 kg/m^3 density, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber exhibited 8%, 11% and 21% decreases in thermal diffusivity respectively in comparison to control FC specimen. Seemingly, the thermal diffusivity values of produced FC strengthened with EFB fiber decrease with increasing volume fractions of EFB fiber (until it reach optimum volume fraction), and their thermal diffusivities were lower than that of the control specimen by about 8–30% for 800 kg/m^3 density, 8-21% for 1100 kg/m^3 density and 6-20% for 1400 kg/m^3 density.

5.3 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.

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Furthermore, 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 [16]. Table 7 shows the specific heat capacity of FC mixes and Fig. 8 visualizes the specific heat capacity of FC with different EFB fiber volume fraction. Generally, the specific heat capacity of cement-based material like FC varies depends on different level of temperature. Hydrated cement paste contains low specific heat capacity. Interestingly, water is very effective to increase the specific heat of FC since water possesses a specific heat capacity of 1.0. Table 7 and Fig. 8 demonstrate that the specific heat capacity of FC increases as the volume fraction of EFB fiber in the mix increases to the optimum value. For 800 kg/m^3 density, the control specimen recorded a specific heat capacity of 863 J/kg·K. Compared to control specimen, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber displayed specific heat capacity enhancement of 872 J/kg·K and 881 J/kg·K correspondingly.

Table .7 Specific heat capacity of FC mixes

Mix	Density		
	800 kg/m^3	1100 kg/m^3	1400 kg/m^3
Control (no fiber)	863 J/kg·K	831 J/kg·K	776 J/kg·K
0.15% EFB	872 J/kg·K	839 J/kg·K	782 J/kg·K
0.30% EFB	881 J/kg·K	846 J/kg·K	789 J/kg·K
0.45% EFB	869 J/kg·K	850 J/kg·K	795 J/kg·K
0.60% EFB	875 J/kg·K	842 J/kg·K	783 J/kg·K

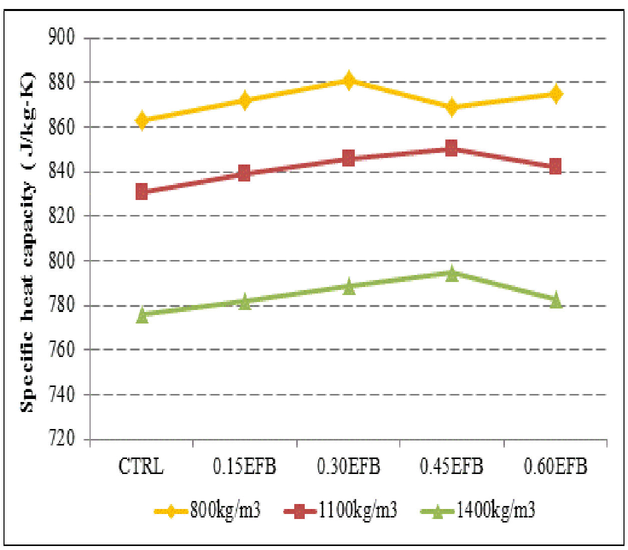

Fig. 8 Specific heat capacity of FC with different EFB fiber volume fraction

Same enhancement pattern of specific heat capacity can be observed for the remaining two densities. The specific heat capacity of FC of 1100 kg/m^3 and 1400 kg/m^3 densities improved consistently with addition of EFB fiber up to the optimum percentage. For 1100 kg/m^3 density, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber exhibited specific heat capacity of 839 J/kg·K, 846 J/kg·K and 850 J/kg·K correspondingly compared to control FC specimen (831 J/kg·K). While for 1400 kg/m^3 density, FC strengthened with 0.15% EFB fiber, 0.30% EFB fiber and 0.45% EFB fiber demonstrated specific heat capacity of 782 J/kg·K, 789 J/kg·K and 795 J/kg·K respectively in comparison to control FC specimen (776 J/kg·K). It is evident when the EFB fiber is added in FC mix, the specific heat of cement paste increases due to the interface between cement and EFB fiber which contribute towards the specific heat components related to the element of vibrations.

VI.CONCLUSIONS

The following conclusions can be withdrawn from this study:

- Thermal conductivity can be used as a measurement for the heat flow in a material when there is a different in temperature. Additionally, the incorporation of EFB fiber in the FC mix also could affect the thermal conductivity. Apparently, the addition of volume fractions of EFB fiber could improve the thermal conductivity values of produced FC reinforced with the EFB fiber (until it reaches optimum volume fraction). The thermal conductivities were lower than the control mix by about 3–30% for 800 kg/m^3 density, 7-20% for 1100 kg/m^3 density and 5-17% for 1400 kg/m^3 density. The results demonstrated a great potential possesses by the EFB fiber to be utilized in cement-based materials such as the FC mix which is beneficial in reducing the thermal property or the transfer of heat in a produced concrete.
- Specific heat capacity can be used as the measurement of heat energy that a substance in a unit quality releases or absorbs when the temperature increases or decreases by 1K. A material would require more energy when the specific heat capacity of a material is higher as to raise its temperature. The specific heat capacity of FC increased simultaneously with the increment of the volume fraction of EFB fiber mix towards the optimum value. It can be emphasized that the specific heat capacity of cement paste tends to increase when the EFB fiber is included in the FC mix due to the interface between EFB fiber and the cement that contribute towards the enhancement of the specific heat associated with vibrations.
- Thermal diffusivity can be used as a measurement for the transient thermal response of a material against the changes in temperature. Generally, concrete-based materials containing high thermal diffusivity would act as an excellent thermal energy diffuser as compared to the materials with low thermal diffusivity which is much slower in diffusing thermal energy. In addition, the increment of volume fractions of EFB fiber would reduce the thermal diffusivity values of produced FC strengthened with EFB fiber (until it reaches optimum volume fraction).

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For instance, the thermal diffusivities were lower than the control specimen by 8–30% for 800 kg/m^3 density, 8-21% for 1100 kg/m^3 density and 6-20% for 1400 kg/m^3 density respectively.

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