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Effect of Steel Fibre Volume Fraction on Thermal Performance of Lightweight Foamed Mortar (LFM) at Ambient Temperature

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ABSTRACT

Lightweight foamed mortar (LFM) has grow into utmost commercial building material in the construction industry for non-structural and semi-structural applications owing to its reduced self-weight, flowability, stability and excellent thermal insulation properties. Hence, this study was conducted with the aims to develop an alternative for conventional concrete bricks and blocks for non-structural and semi-structural applications of masonry. Lightweight foamed mortar (LFM) is either a cement paste or mortar, relegated as lightweight concrete, in which suitable foaming agent entraps the air-voids in mortar. It therefore has a wide range of applications such as material for wall blocks or panels, floor & roof screeds, trench reinstatement, road foundations and voids filling. This research focuses on experimental investigation of thermal properties of LFM with inclusion of relatively low volume fraction (0.2% and 0.4%) of steel fibre at ambient temperature. There are three parameters will be scrutinized such as thermal conductivity, thermal diffusivity as well as the specific heat capacity. There are two densities of 600kg/m^3 and 1200kg/m^3 had been cast and tested. The mix design proportion of LFM used for cement, aggregate and water ratio was 1: 1.5:0.45. The experimental results had indicated that the thermal conductivity, thermal diffusivity and specific heat value slightly higher than control mix due to the addition of steel fibres. For instance, thermal conductivity, diffusivity and specific heat of 600 kg/m^3 density control mix were 0.212W/mK, 0.477mm^2/s and 545 J/kg◦C respectively. When 0.2% volume fraction of steel fiber was added in the mix of 600 kg/m^3 density, the value of thermal conductivity, diffusivity and specific heat were increased to 0.235W/mK, 0.583mm^2/s and 578 J/kg◦C correspondingly. This is due to the characteristic of the steel fibre application in which steel fibre is good as heat conductor and excellent in absorbing heat. Therefore there is a potential of utilizing steel fiber in cement based material like LFM for components that needs excellent heat absorption capacity.

Keywords:

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Thermal performance, foamed concrete,
lightweight, steel fibre, heat conductor

1. Introduction

Lightweight concrete and normal concrete have not much difference. The difference between normal concrete and lightweight foamed mortar (LFM) is there are no coarse aggregates in making of lightweight product. It is a product that consists of entrapped air bubble that acts as the aggregate thus, making it better products in terms of concrete flow-ability leading to a lighter product, workability, thermal properties, flexibility etc [13]. The application of LFM can be used in almost every parts of building from superstructure right down to the substructure, including wall panel and roofing [8]. Apart of being relatively lighter than conventional concrete with a dry density of 300 kg/m3 to 1800 kg/m3. Which giving additional qualities such as nail-ability, lessened the dead weight, reduces the foundation size, labour, transportation and operating costs [9]. The strength of LFM highly depends on the porous of structure of the concrete [10].

Nowadays, interest on the natural fibre can be seen progressively in Malaysia since it has possesses ecological and economical in construction industries. Various natural fibres namely jute, bamboo, abaca, kenaf etc. are widely used in industries for making lightweight concrete [5]. From a structural point, the primary reason for adding fibres to improve structural properties of concrete through the fibres ability. Fibres act as a multi-dimensional reinforcement and it enhances the bond between the matrix that in turn increases the tensile strength and structural integrity of the concrete [11].

2. Mix Design and Experimental Setup

There are 6 mixes were designed, cast and tested with a cement-aggregate ratio of 1:1.5 and water-cement ratio of 0.45 and steel fibre volume fraction of 0%, 0.2% and 0.4% for both densities (600kg/m^3 and 1200kg/m^3). Table 1 demonstrates details of mix design used for LFM in this study. Control mix was prepared to determine the effectiveness of the percentage of steel fibre for each mix design.

Table 1
Details of mix design

Mix Design	Control mix 600kg/m^3	Batch A 600kg/m^3	Batch B 600kg/m^3	Control mix 1200kg/m^3	Batch A 1200kg/m^3	Batch B 1200kg/m^3
Water-cement ratio	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
Target Density	600kg/m^3	600kg/m^3	600kg/m^3	1200kg/m^3	1200kg/m^3	1200kg/m^3
Steel Fibre	0%	0.2%	0.4%	0%	0.2%	0.4%

The test was performed on specimens of cylinder shape with a diameter 75mm and high 20mm using TPS 2500S thermal test machine. The enviably short test times and small power input of this machine make it an excellent choice for performing measurements on saturated samples, as it precludes vapour loss or convection from persuading results. Figure 1 shows the set-up to quantity the thermal properties of diffusion concrete samples with the Hot Disk TPS 2500 S.

This TPS 2500S thermal test machine has different size of hot disk sensor depend on the sample dimension. For this particular study, 6.403-diameter size of hot disk sensor is used with output of power 0.12W and measuring time 20 second (Figure 2). Furthermore, for each mixture, two specimens were tested. All the data obtained via computer delivered by thermal test machine. The samples were positioned in the oven at a temperature of 105°C±5°C for 24 hours to remove the moisture content in it as the moisture will lead to a high heat transfer rate (Khan, 2002). The censor was placed between two samples to determine the thermal conductivity. Measurement, probing depth, power and time needed to be set accurately by allowing the accepted rate before the test. The thermal diffusivity (mm^2/s) and specific heat (J/kg◦C) were verified together with thermal conductivity (W/mK) during the test.

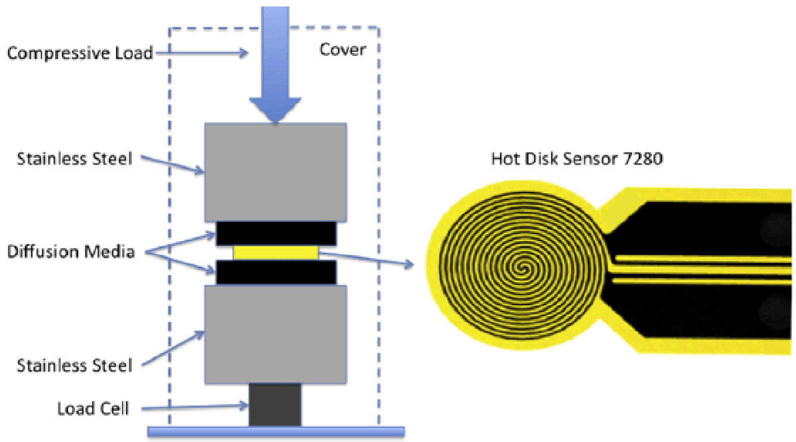

Fig. 1. Experimental set-up to quantity the thermal properties of diffusion concrete samples with the Hot Disk TPS 2500 S machine [12]

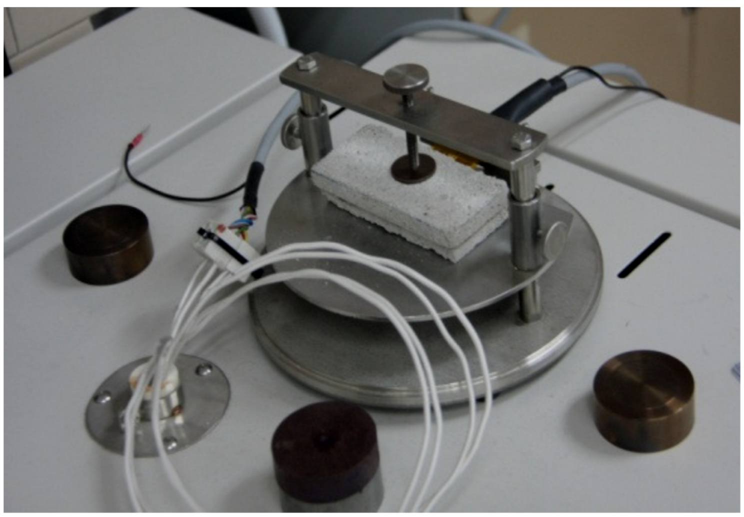

Fig. 2. Set-up on hot disk thermal constant analyser

3. Results and Discussion

The aim of the thermal properties tests are to establish and scrutinise the thermal transport properties including thermal conductivity, thermal diffusivity and specific heat capacity.

3.1 Thermal Conductivity

Figures 3 and 4 indicate the data of thermal conductivity of different densities in unit W/mK. Based on Figure 3 and Figure 4, it can be seen that the thermal conductivity increase with addition of the steel fibre compared to control mix of LFM. For density of 600kg/m^3 with steel fibre volume fraction of 0.2% has value 0.235 W/mK while additive 0.4% of steel fibre has value 0.248 W/mK showed an increase in thermal conductivity than the control mix. On the other hand, thermal conductivity in density 1200kg/m^3 also increase affect from the addition of steel fibre. The steel fibres those volume fraction of 0.2% has a value of thermal conductivity 0.496W/mK and the volume fraction of 0.4% is 0.529W/mK.

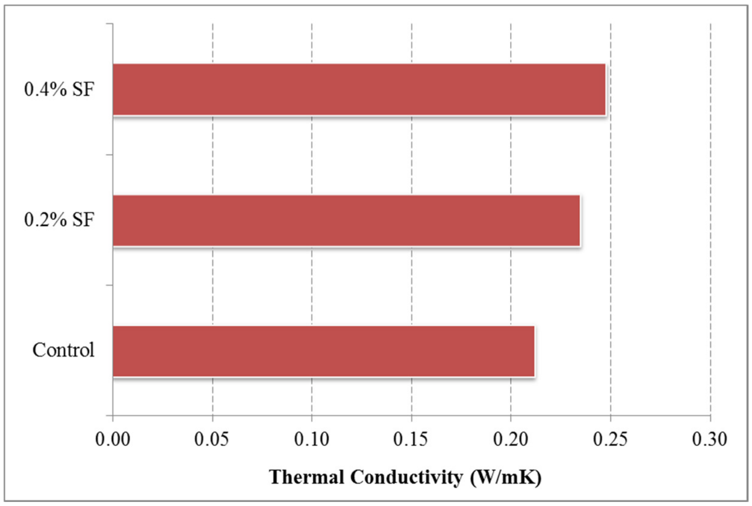

Fig. 3. Thermal conductivity of 600kg/m^3

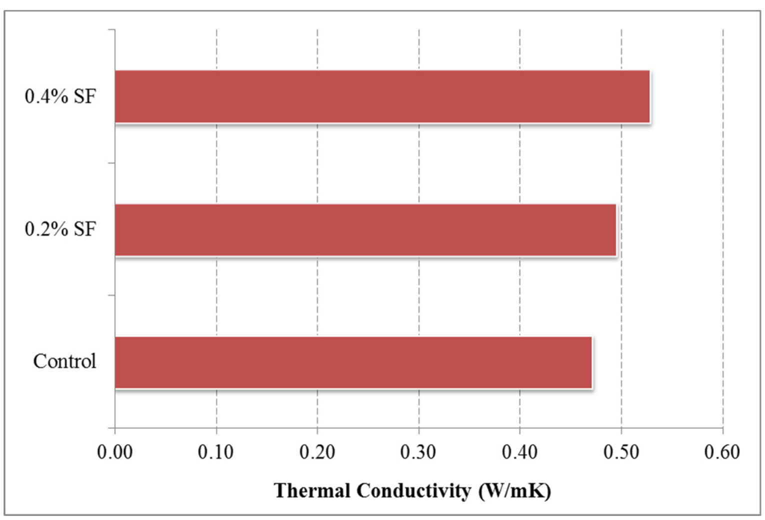

Fig. 4. Thermal conductivity of 1200kg/m^3

Compare to the control mix only 0.454W/mK. Moreover, thermal conductivity of 1200kg/m^3 density is higher than the 600kg/m^3 density. In general, LFM has good thermal insulation properties due to the low density of concrete. From the data recorded the thermal conductivity value slightly higher due to the addition of steel fibres. It is because of the characteristic of the steel fibre application which is steel fibre is good in heat conductor. Moreover, addition of the steel fibre on the mix was affect the formation and size of pores to the specimen [6]. From the statement above its can proved that used of steel fibre will increase the value of thermal conductivity. Based on the result obtain the different density of lightweight foamed concrete also enhancement the value of thermal conductivity. It's proved that high density of foamed concreted will have smaller porosity value compare to low density foamed concrete, Hence, this will influence the thermal conductivity due to the different size and formation of pores on the microstructure formation of lightweight foamed concrete [2].

3.2 Thermal Diffusivity

Figures 5 and 6 show the results of thermal diffusivity of different densities in unit mm^2/s. It can be clearly seen from both figures that the thermal diffusivity increase with the addition of steel fibre compared to the control mix. For 600kg/m^3 density, the steel fibre volume fraction of 0.2% has value 0.583mm^2/s while additive 0.4% of steel fibre has value 0.661 mm^2/s showed an increase in thermal diffusivity than the control mix. On the other hand, thermal diffusivity in density 1200kg/m^3 also increase affect from the addition of steel fibre. The steel fibres those volume fraction of 0.2% has a value of thermal diffusivity 0.352 mm^2/s and the volume fraction of 0.4% is 0.379 mm^2/s compare to the control mix only 0.332 mm^2/s.

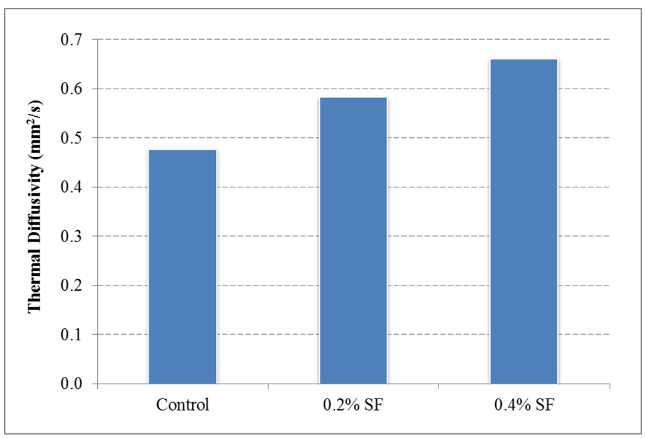

Fig. 5. Thermal diffusivity of 600kg/m^3

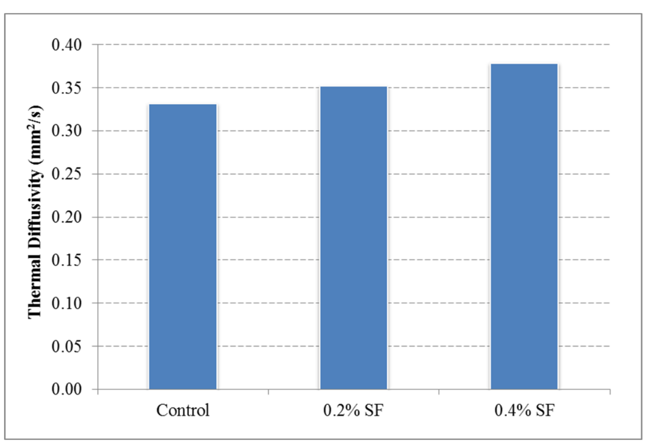

Fig. 6. Thermal diffusivity of 1200kg/m^3

Moreover, from both of the graph has been seen that thermal diffusivity on density of 1200kg/m^3 are higher than density of 600kg/m^3. It should be pointed out that the thermal diffusivity increased affect from addition of volume fraction of steel fibre. That proved that steel fibre causes heat time movement faster than the control mix due to the characteristic of steel fibre where it absorbs heat more quickly [14]. Besides, such statement previously high density of foamed concreted will have smaller porosity value compare to low density. Therefore this will stimulus the thermal diffusivity due to the different size and formation of pores on the microstructure formation of lightweight foamed concrete. It can be conclude that the lower density of foamed concrete the lower value of thermal conductivity.

3.3 Specific Heat Capacity

Figures 7 and 8 show the results of specific heat capacity of different densities in unit J/kg◦C. Based on Figure 7 and Figure 8, it can be seen that 0.2% and 0.4% fraction of steel fibre increase the specific heat compare to the control LFM. The 600kg/m^3 density grant the value of 578 J/kg◦C for 0.2% volume fraction of steel fibre and 0.4% of steel fibre has value 619 J/kg◦C showed an increase in specific heat capacity than the control mix.

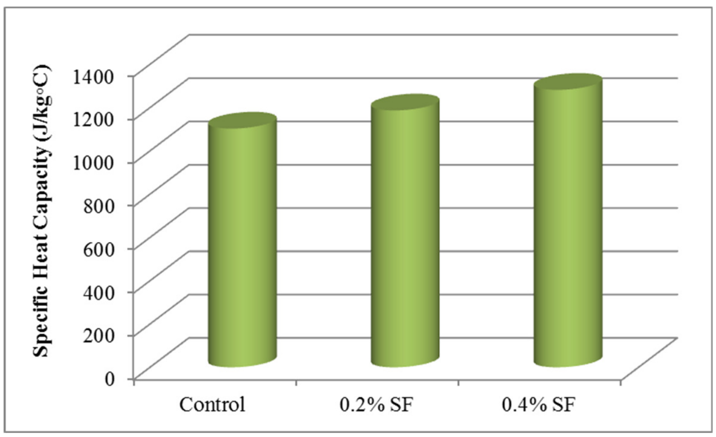

Fig. 7. Specific heat capacity of 600kg/m^3

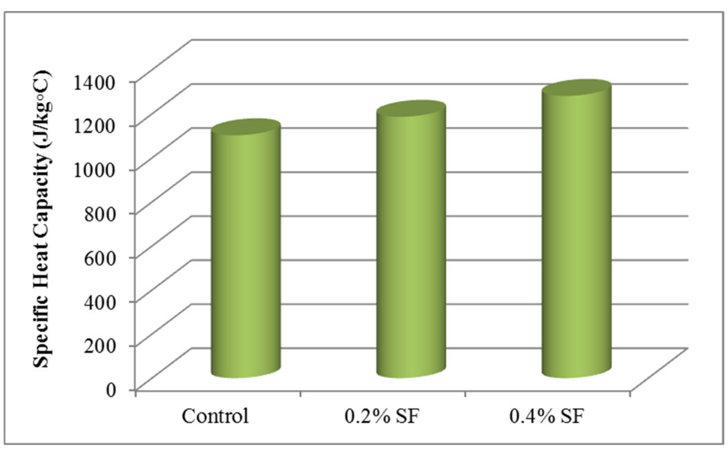

Fig. 8. Specific heat capacity of 1200kg/m^3

On the other hand, specific heat in density 1200kg/m^3 also increase affect from the addition of steel fibre. The steel fibres those volume fraction of 0.2% has a value of specific heat 1187 J/kg◦C and the volume fraction of 0.4% is 1282 J/kg◦C. Compare to the control mix only 1103 J/kg◦C. Visually as well, Density of 1200kg/m^3 has higher specific heat than the density of 600kg/m^3 lightweight foamed concrete due to the difference of density of lightweight foamed concrete. The fact, steel fibre will cause high temperature when exposed to hot environment. Therefore, from the data analysis that proved steel fibre is good at absorb heat and the specific heat capacity will be increase when the steel fibre are used in foamed concrete due of steel fibres is low properties in term of thermal properties [7].

4. Conclusion

This research focuses on experimental investigation of thermal properties of LFM with inclusion of relatively low volume fraction (0.2 % and 0.4 %) of steel fibre at ambient temperature. There are three parameters have be scrutinized such as thermal conductivity, thermal diffusivity as well as the specific heat capacity. There are two densities of 600kg/m^3 and 1200kg/m^3 had been cast and tested. The mix design proportion of LFM used for cement, aggregate and water ratio was 1: 1.5:0.45. The experimental results had indicated that the thermal conductivity, thermal diffusivity and specific heat value slightly higher than control mix due to the addition of steel fibres. This is due to the characteristic of the steel fibre application in which steel fibre is good as heat conductor and excellent in absorbing heat

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