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Thermal Conductivity of Micro Steel Fiber Reinforced Concrete

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Abstract: There is a demand to improve energy efficiency through passive design and thermal insulation of building using micro steel fibers. Therefore, this study utilized micro steel fiber in concrete construction. The objective was to determine the thermal conductivity of micro steel fiber concrete and to evaluate the relationship between concrete density and porosity. Micro steel fibers were used as an admixture in concrete grade 40 with different percentages from 0.5% to 1.25% by weight. The thermal conductivity tests were conducted using Hot Guarded Box after 28 days of curing. In addition, all specimens were tested for density and water absorption in order to establish the relationship between the parameters. The result shows that micro steel fiber concrete's thermal conductivity increased moderately with the increase of micro steel fiber percentage. The percentage of water absorption of micro steel fiber concrete decreased when the density of concrete increased. Based on the results, it can be concluded that, the use of micro steel fibers in concrete in Malaysia construction industries is unsuitable due to Malaysia's hot climate.

Keywords: Micro Steel Fiber, Fiber Reinforced Concrete, Thermal Conductivity, Density, Water Absorption

1. Introduction

Concrete is one of the most popular building materials used in the civil engineering. It mixes with cement, water, fine aggregates, coarse aggregates, and adding fiber content to enhance concrete's performance. These ingredients are added depending on the precise mixing speed and ratio [1]. Concrete is also commonly used as a building material because of its high compressive strength, long life, durable and low cost [2]. As the construction industry rapidly grows, it increases the demand for high-rises and long-life concrete structures. The benefits of using concrete are high strength, high water resistance, strong thermal strength for concrete, low maintenance, and long service life [1].

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Global warming has led the world's to devastating environmental disasters. Global warming cannot be immediately stopped, but efforts can be made to minimize its effects [3]. One of the contributors to global warming is the greenhouse effect. The greenhouse effect is when heat energy is absorbed and distributes by the gases that form a planet's atmosphere. The primary gasses contributing to this effect include water vapor, methane, and carbon dioxide. In creating comfortable indoor areas, proper isolation is essential. There are crucial sections, such as walls, roofs, floors, and others usually occupied by people. Besides, the main structures, other structure such as columns and walls, also play an essential role in reducing the building's temperature and radiation [4]. Usually, heat can typically be transmitted by conduction, convection, and radiation [5]. Besides the temperature regulation, steel fiber concrete in the column, beam, and walls of the construction help maintain a uniform building temperature [4].

Thermal conductivity is the steady-state and transient flow rate through a unit area in the direction of the unit temperature gradient of a homogenous material in unit W/mK [4]. Steady-state is a continuous heat transfer that does not depend on temperature or heat flow. The transient approach relies on time and temperature variations over time [4]. Thermal conductivity is used for evaluating the steady heat flow or transient flow (depends on the method used) of a substance at a rate for the difference of unit temperature and area [5]. Adding the mixing fiber amount into concrete would substantially reduce thermal loss and improve its thermal characteristics performance [6]. The heat transmission decreases the quantity of concrete with a low thermal conductivity that increases building energy utilization. To enhance thermal effectiveness with minimal impact on existing properties, the addition of steel fiber in the concrete mixture has many essential effects, increasing the flexural strength and tensile strength [7].

This study aims to determine micro steel fiber reinforced concrete thermal conductivity. This study also aims to develop a relationship between density, water absorption, and micro steel fiber concrete's thermal conductivity.

2. Materials and Methods

2.1 Materials

The materials used in this research included Ordinary Portland Cement (OPC), the maximum size of Fine Aggregates (FA) is 5mm, the maximum size of Coarse Aggregates (CA) is 20mm, Superplasticizer (SP), water and Micro Steel Fiber (MSF). The aspect ratio (length/diameter) of this micro steel fiber used in this study is 50 with 0.25 mm diameter and 12.5mm in length. The micro steel fiber used is shown in Figure 1, and the properties of MSF provided by the manufacturer are shown in Table 1.

Figure 1: Micro steel fiber

Table 1 shows the properties of micro steel fiber used in this research. Micro steel fiber had greater tensile strength, and it significantly develops a bond with the cement, coarse and fine aggregate in the mixture. Among factors that will enhance the performance of micro steel fiber reinforced concrete are the shape of micro steel fiber, length, diameter, aspect ratio, and percentage used. According to [8], thermal conductivity of the MSF reinforced concrete was largely influenced by the aspect ratio of MSF. Steel fiber with higher thermal conductivity replaces the air voids and pore spaces in the concrete, and this caused the increment in thermal K-value of concrete [8].

Table 1: Properties of micro steel fiber (as provided by the manufacturer)

Properties	Value
Diameter	0.25 mm
Length	12.5 mm
Tensile strength	2930 MPa

2.2 Methods

A total of 15 cube (100 x 100 x 100 mm) specimens were prepared in this study. Five mixes with MSF ratios of 0% (control), 0.5%, 0.75%, 1.0%, and 1.25%, denoted by Control, MSF0.5, MSF0.75, MSF1.0, and MSF1.25 as in Table 2 were prepared. The targeted strength of the concrete is 40MPa with 0.47 water-cement ratio. After demoulding of concrete specimens, the specimens were water cured for 28 days before testing. Determination of concrete density, water absorption and thermal conductivity of all the specimens were in accordance with BS EN 12390-7 [9], BS EN 1881-122 [10] and BS EN 12667 [11], respectively. In addition, the slump test as per BS 12350-2 was conducted for every mixes. Table 2 shows the mixed proportion of the concrete.

Table 2: Mix proportions

Mix	Cement (kg)	Water (kg)	FA (kg)	CA (kg)	MSF (kg)	SP (kg)
Control	3.24	1.56	4.36	10.05	0	0
0.5% MSF	3.24	1.56	4.36	10.05	0.034	0.032
0.75% MSF	3.24	1.56	4.36	10.05	0.051	0.032
1.0% MSF	3.24	1.56	4.36	10.05	0.067	0.032
1.25% MSF	3.24	1.56	4.36	10.05	0.084	0.032

2.3 Thermal conductivity test

Thermal conductivity (k-value) is the substance's ability to transfer heat energy. Transient method is often used for heterogeneous materials like concrete [3]. Generally, the thermal conductivity test was conducted to determine the suitability of materials as thermal insulation for a building structure [3]. There are two ways to measure thermal conductivity, namely steady-state and transient heat. Steady-state is commonly used for homogenous materials. This method is more time consuming. However, this method is more accurate compared to the transient method. For transient, it is more suitable for heterogeneous materials with moisture content. The advantage of the transient method is the result incorporate the moisture content in that particular materials. However, researcher need to repeat the test several time in order to get more precise results. Based on previous researches, many researchers prefers

using transient method for concrete due to its heterogeneous nature. Steady-state techniques are also useful if the material temperature does change over time [13].

The Hot Guarded Box was used in this study. However, the K-value need to be calculated from Equation 1 [12].

$$k = \frac{Ø \times d}{A \times \Delta T} \quad \text{Eq. 1}$$

where,
Ø = is the average power supplied to the metering section of the heating unit;
d = the average specimen(s) thickness [m];
ΔT = the differences specimen(s) temperature;
A = the metering area (central area of the specimen delimited by the centerline of the gap of the heating unit)

3. Results and discussion

3.1 Workability

The fresh concrete workability was determine using the slump test. As shown in Figure 2, with increasing values of micro steel fiber, the slump value decreased. The slump value of concrete containing 0.5% micro steel fiber compared to the control specimen (without micro steel fiber) showed a reduction, from 58mm to 45mm. Increased percentages of micro steel fiber reduced the workability of the concrete. This is because the micro steel fiber particle has a fine shape, leading to a higher surface area, hence reducing the mixes' workability. Besides, micro steel fiber particles cause a tendency to interlock between mixing, which leads to less workability in the mixtures [14].

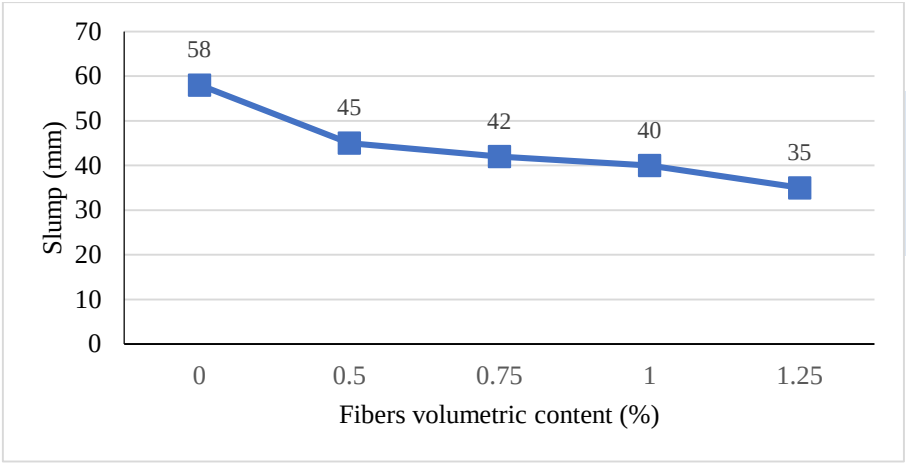

Figure 2: Slump test result

3.2 Density

The incorporation of micro steel fiber in the concrete mixture influences the density. The density of concrete increased as the percentage of micro steel fiber increased as shown in Figure 3. The MSF0.5 and MSF1.25 had approximately 2410 kg/m³ and 2480 kg/m³ in density, respectively increases by 1.2% and 4.2% compared to normal concrete. This is due to MSF that consist of smaller particles. The smaller particles tend to fill in the voids thus making the concrete denser. Hence increasing the density of the concrete as the amount of the MSF increased.

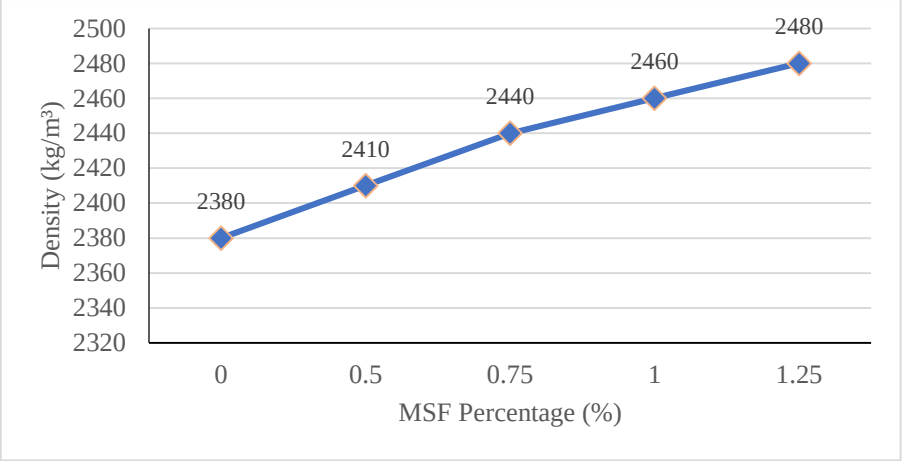

Figure 3: Density test results

3.3 Water absorption

Water absorption of concrete with MSF is shown in Figure 4. It can be observed that the water absorption of MSF0.5 decreasing drastically compared to normal concrete. However, the result shows water absorption decreasing moderately on MSF0.75, MSF1.0, and MSF1.25. The reduction in water absorption can be associated with MSF filling in every void between coarse and fine aggregates. Moreover, water absorption can be interpreted as an indication of concrete air voids [7]. According to [9], the fine size of MSF was used as filler between coarse aggregate and fine aggregate and somehow reduced air voids in concrete [9].

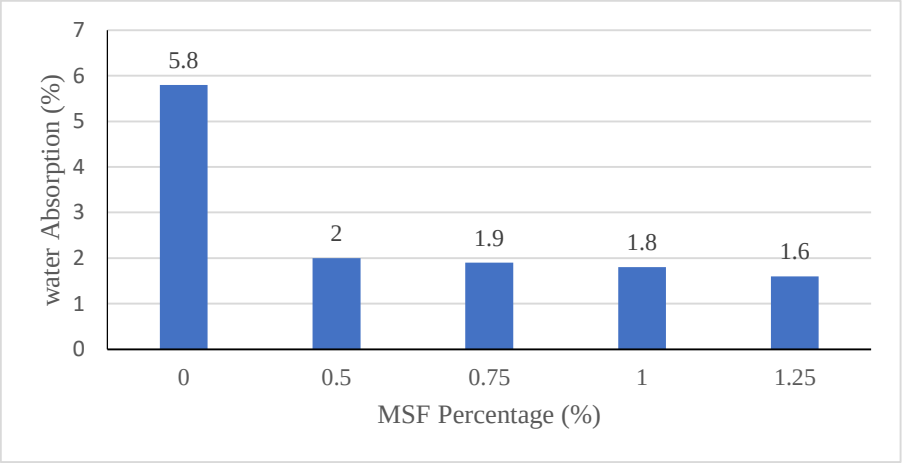

Figure 4: Water absorption test results

3.4 Thermal conductivity

Figure 5 shows K-value increased from MSF0.5 to MSF1.25 with 2.19 W/mK, 2.34 W/mK, 2.42 W/mK, and 2.52 W/mK, respectively. However, the K-value of normal concrete shows a significant decrease compared to MSF0.5. Increasing the amount of MSF resulted in increased K-value. This due to the nature of MSF itself. MSF is made from copper and copper is known as one of the materials that is good in thermal conductivity. Based on the result, the K-value for MSF reinforced concrete is 1.26 W/mK – 2.52 W/mK. Based on previous researcher [15,5], thermal conductivity of concretes with high density and reinforced steel fiber is from 2.0 W/mK to 3.2 W/mK.

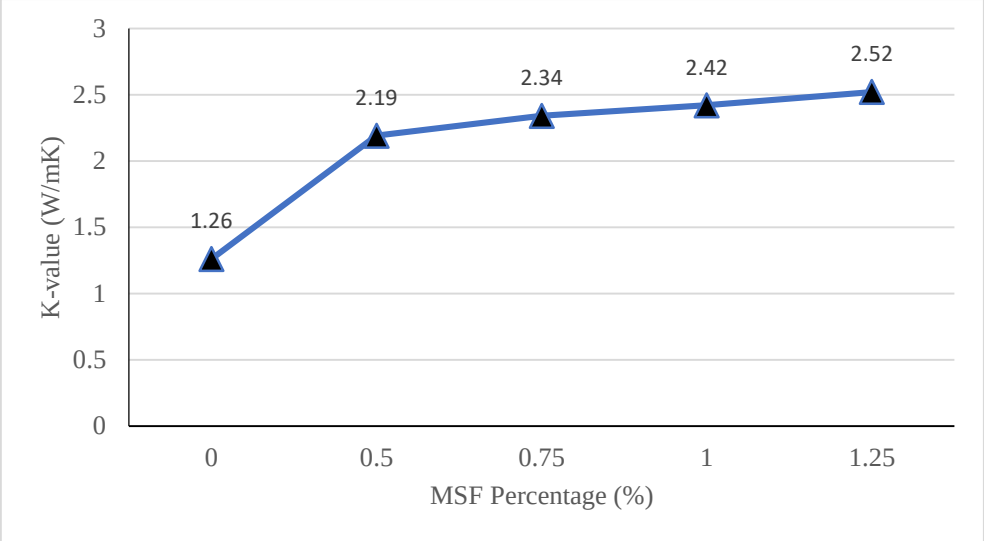

Figure 5: Thermal conductivity test results

3.5 Relationship between density, water absorption of concrete, and thermal conductivity

The thermal flow is influenced by solid matter and by void material. In contrast, the voids' air temperature conductivity is better than solids, which reduces the whole material's thermal conductivity [15]. Generally, heat can be transferred by a process called heat conduction. Conduction is when heat transfer within a solid or between solid objects in thermal contact [5]. Then, high density in solid material will reduce the air voids. Thus, the fewer percentages of air voids in high-density solid material will increase the heat conduction, and heat is not transmitted efficiently to the bulk of air. It is mainly the very low density of air that makes them bad conductors of heat. In solids, atoms and molecules are densely packed, and energy transfer has much smaller distances to happen [17]. In general, good conductors of electricity metals like copper from MSF are also gives good heat conductors. Inside heterogeneous material like concrete should have a good air void with a minimal percentage for reducing thermal. Using MSF in concrete will increase density, reduce air voids, increase thermal conductivity, and absorb heat from outside into the inside building. Besides, micro steel fiber's thermal conductivity had a higher K-value to indicate MSF concrete increases [16].

Furthermore, the increase in thermal conductivity is related to the air voids in concrete that results in more density. The decrease in water absorption indicates less porosity inside concrete due to the incorporation of micro steel fiber because of its small size to fill the voids. Its physical properties do not affect the water-cement ratio. However, concrete with incorporation MSF will easily flow the heat from outside to inside the building. It may increase energy consumption, affect the building's thermal comfort, and disturb the human health who's living inside the building. However, mostly structure on-site there has low-density in-situ concrete due to poor compaction. Still, concrete with incorporation MSF, which has a high density in a saturated specimen, is also good to increase density in-situ concrete. Besides, MSF concrete also can be considering used at no people's living, such as a tunnel and dam.

4. Conclusion

This research was carried out to determine the workability, thermal conductivity, density, and water absorption of concrete containing micro steel fiber. Based on the results obtained, the following conclusion was drawn:

- With the inclusion of micro steel fiber in concrete, workability was reduced. For instance, the slump value was decreased by 28% compared to normal concrete when 0.5% of micro steel fiber was added.
- With increasing density of micro steel fiber, the water absorption was decreased.
- When the percentage of micro steel fiber increases, the thermal conductivity value of micro steel fiber concrete also increases, this can be attributed to the thermal properties of micro steel fiber itself and affected by heat transfer due to the high density of micro steel fiber.

Based on this study findings, it can be concluded that the used micro steel fiber in concrete is good to increase the density and reduce the porosity of concrete. However, it increase the thermal conductivity of the concrete. Higher K-value will affect the thermal comfort of the building inside. It will then increase the building's energy consumption and lead to Urban Heat Island phenomenon.

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