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Thermal conductivity of lightweight foamed concrete filled fly ash

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Abstract. Wall is the wider component of high-rise building to exposed the sunshine than roof. The building wall in tropical countries receives the solar heat all day and it makes temperature rise of its room and becomes less comfortable. Therefore, a wall with good thermal insulation is needed for buildings in tropical countries. Lightweight foamed concrete (LFC) can be used as a wall brick substitution as well as thermal insulator. The experimental research about LFC was investigated using FA and foam content to the thermal conductivity of LFC. The investigations were performed through the measurement of thermal conductivity, material density, and observation to the morphology of LFC surface. The LFC samples were varied in volume fraction of foam and FA in mortar. The result shows that the increase in volume fraction of foam in all variations of FA content decreases its thermal conductivity. In contrast, the increase of FA content in LFC results in an increase in thermal conductivity until 45 wt% of FA content, then it decreases as the addition of FA. Thus, the optimum thermal conductivity of the LFC was obtained by FA of 45 wt%. The relationship between thermal conductivity and LFC density shows that any increase in LFC density resulted in an increase in thermal conductivity. Otherwise, any decrease in LFC density resulted in a decrease in thermal conductivity.

1. Introduction

Concrete is a construction material that widely used for wall or building structures because of its formability, workability, durability and strength. There are two kind of concretes in accordance with its material density. First is the normal concrete that have material density of 2,200 – 2,500 kg/m³. The second one is the light concrete that have material density of 300 – 1,800 kg/m³ [1].

The wall is the widest component of the high rise building than the roof. Both components are directly exposed to the sun's heat. The building walls in tropical countries (near to the equator) receives the solar heat all day long then make the temperature in the room become rising and less comfortable. Moreover, the air temperature of urban area in the night reached 31 °C - 32 °C due to global warming [2]. Therefore, a wall with good thermal insulation is needed for buildings in tropical countries.



The high thermal insulation of the walls is due to its low thermal conductivity which results in the ability of it to inhibit the thermal transmittance. Lightweight foamed concrete (LFC) is a building material with low weight, high durability, and excellent thermal insulator [3]. LFC can be produced by using the lightweight aggregate sand and the foam into concrete mortar. LFC that has a minimum foam volume of 20% to the cement mortar thus results lower density than the normal concretes [4].

The excellent of LFC thermal insulation is due to its low thermal conductivity. The LFC thermal insulation capability was 4-6 times better than the bricks [5]. Contrary, the normal concrete was require 5 times in thickness of the lightweight ones to achieve same thermal conductivity [6]. Jones and McCarthy [7] proved that the thermal conductivity of LFC is 5 to 30% lower than the normal concrete.

The high porosity value result in low density of the LFC. Hence, the LFC density is the important role in determining the thermal conductivity of it [8]. The pore structure of the LFC is the cause of this material having good thermal insulation [9]. The increase in foam content of LFC results in lower the density, the compressive strength, and the thermal conductivity [10]. The thermal conductivity of dry 600-1,600 kg/m³ LFC is between 0.1 to 0.7 W/mK [7]. LFC with the cement-sand ratio of 2:1, water-cement ratio of 0.5, foaming agent of Noraite PA-1, and dry density of 600-1,400 kg/m³ was result in the thermal conductivity of 0.22 – 0.45 W/mK [8].

The fly ash (FA) plays a role in the void distribution of the LFC by provides a separation layer between the cavities thus results in smaller voids [11]. The FA in LFC is improving the structure of it and producing higher compressive strength than other materials [12]. LFC with 2wt%, 3wt%, and 4wt% of foam combined with 20wt% of FA yields the material density of 1,613 kg/m³ and the thermal conductivity of 0.885 W/mK [13]. The result is same with the brick thermal conductivity of 0.87 W/mK. The LFC thermal conductivity with the cement-sand ratio of 1:1.5 and added with pulverized fuel ash (PFA) of 15% and 30% results the thermal conductivity of 0.44 W/mK and 0.41 W/mK, respectively. The addition of 25% silica fume and 40% palm oil fuel ash (POFA) in same of the cement-sand ratio were result in thermal conductivity of 0.46 W/mK and 0.44 W/mK, respectively [14].

The recently studies show that the foam and the FA content can influence the thermal conductivity of the LFC. However, the optimum value of the FA content in a certain foam content is not yet known. Therefore, the aim of study is to investigate the influence of FA content to the thermal conductivity of the LFC. The investigations were performed using experimental methods through the measurement of the thermal conductivity, the material density, and observation to the morphology of the LFC surface.

2. Experimental

2.1. Materials

The samples of LFC were made from the Portland Cement Composite (PCC), the aggregate sand, the fly ash (FA), the water, and the foaming agent. The PCC was supplied by Holcim. The aggregate sand used has a maximum grain size of 4.75mm. The FA was supplied from the waste product of Cilacap Steam Power Plant, Central Java, Indonesia. The synthetic foaming agent was supplied from Kip Light.

2.2. The LFC composition

The LFC samples were made with a cement and sand ratio of 1:2. Variations of LFC samples were determined on the volume fraction of foam in the mortar that is 30 vol%, 40

vol%, and 50 vol%. While at each volume fraction of foam there are weight fraction variation of FA that is 0 wt% (FA0), 15 wt% (FA15), 30 wt% (FA30), 45 wt% (FA45), 60 wt% (FA60), and 75 wt% (FA75) of aggregate sand weight. Table 1 shows the composition of the LFC samples.

2.3. Preparation of the LFC samples

The foam was prepared to from a mixture of foaming agent and water with the ratio of 1:40. The foam was produced in a foam generator in a compressed air environment, thus resulting the foam density of 80 g/L [4], [15]. The cement, aggregate sand, and FA were mixed in a mechanical mixer at 20 rpm for 3.5 min, and then water was added to the mixture while the mixer is still rotating for 3 min, thus resulting in a homogeneous paste. Furthermore, the appropriate foam composition was added into the mixed paste for 2.5 min resulting LFC paste. The LFC paste was poured into appropriate molding in accordance with sample test dimension. After 24 h, the LFC samples were removed from the mould then it was stored in room temperature in 25 days for the cure. Finally, the LFC samples were oven-dried in approximately 60°C for 2 days and then stored in room temperature.

Table 1. The LFC samples code and composition

Sample code	Foam (vol%)	Cement (kg)	Sand Aggregate (kg)	FA (kg)	Water (kg)
FA0	30	434.48	868.97	0.00	217.24
FA15		431.43	733.44	129.43	215.72
FA30		428.43	599.98	257.06	214.21
FA45		425.46	468.01	382.92	223.37
FA60		422.54	338.03	507.04	227.11
FA75		419.65	209.83	629.48	233.96
FA0	40	372.41	744.83	0.00	186.21
FA15		369.80	628.66	110.94	184.90
FA30		367.22	514.11	220.33	183.61
FA45		364.68	401.15	328.21	191.46
FA60		362.18	289.74	434.61	194.67
FA75		359.70	179.85	539.55	200.53
FA0	50	310.35	620.69	0.00	155.17
FA15		308.17	523.88	92.45	154.08
FA30		306.02	428.43	183.61	153.01
FA45		303.90	334.29	273.51	159.55
FA60		301.81	241.45	362.18	162.22
FA75		299.75	149.88	449.63	167.11

2.4. Thermal conductivity test

Thermal conductivity measuring apparatus of HVS-40-200SE model from Tokyo Meter Co. Ltd was used to obtain thermal conductivity of the LFC samples. The dimension of LFC

samples were 40mm in diameter and 8mm in height. The thermal conductivity (k) can be calculated according to Eq. 1 [16].

$$k = \frac{q \cdot L}{A \cdot \Delta T} \quad (1)$$

The k is thermal conductivity in W/mK, q is conduction heat transfer rate in W, L is the sample thickness in m, A is the sample surface area in m^2 , and ΔT is the temperature difference in K.

2.5. Material density test

The dimension of LFC samples for the material density test was 75mm in diameter and 150mm in height. The density test was performed on 4 LFC samples at each variation of aggregate composition (Table 1). The material density of LFC can be calculated according to Eq. 2. The BJ is material density in kg/m^3 , W is the sample weight in kg, and V is the sample volume in m^3

$$BJ = \frac{W}{V} \quad (2)$$

2.6. The morphology of material

Scanning electron microscope (SEM) was used to observe the morphology of the LFC samples surface. The observed samples were FA30 in each foam volume fraction.

3. Results and Discussions

3.1. The relationship of thermal conductivity and foam volume fraction

The increase in volume fraction of foam in all variations of FA content (Fig. 1) shows a decrease in thermal conductivity. The highest thermal insulation is produced by LFC with the lowest thermal conductivity i.e. FA0 at 50vol% of foam. While the lowest thermal insulation was produced by LFC with the highest thermal conductivity i.e. FA45 at 30vol% of foam. The FA0 at 50vol% and FA45 at 30vol% was resulted thermal conductivity at 0.16 W/mK and 0.42 W/mK, respectively.

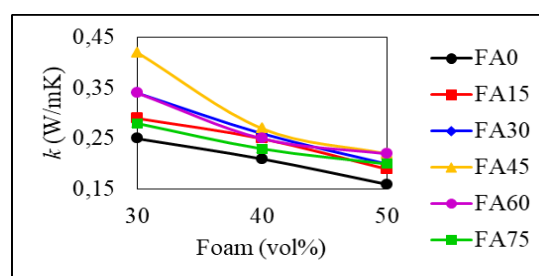


Figure 1. The volume fraction of foam (foam (vol%)) to thermal conductivity (k) of the LFC.

3.2. The relationship of thermal conductivity and weight fraction of FA

In accordance with Fig. 2, the increase of FA content in LFC resulted in an increase in thermal conductivity weight fraction of 45wt%, then decrease as the addition of FA. Thus, the optimum thermal conductivity of the LFC (30vol%, 40vol%, and 50vol% of foam) was obtained by FA of 45wt%. The highest thermal conductivity at 30vol% of foam was produced by FA45 at 0.42 W/mK. The 40vol% of foam was produced the highest thermal conductivity at FA45 of 0.27 W/mK. While the 50vol% of foam was produced the highest thermal conductivity in FA composition of FA45 and FA60 at 0.22 W/mK.

Cenospheric particle morphology of fly ash particles, which increases the heat flow path (Othuman Mydin, 2010). The use of lightweight aggregates with low particle density in combination with artificially introduced air-voids in the mortar matrix has been observed to be advantageous in reducing thermal conductivity) [19].

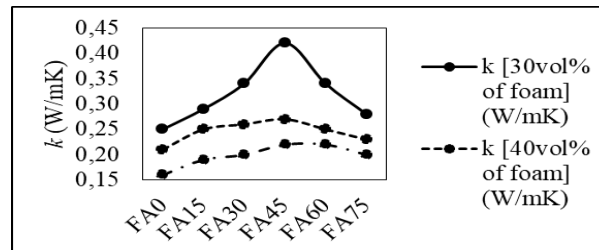


Figure 2. The weight fraction of FA to thermal conductivity (k) of the LFC.

3.3. The relationship between thermal conductivity and LFC density

Fig. 3 shows the relationship between thermal conductivity and LFC density. In each volume fraction of foam variations (Fig. 3 (A), (B), and (C)) was found that any increase in LFC density resulted in an increase in thermal conductivity. In contrary, any decrease in LFC density resulted in a decrease in thermal conductivity.

The lower density lightweight foamcrete signifies larger porosity value; hence density plays an important role in determining the thermal conductivity of foamcrete. The low density of LFC is significantly influenced by the magnitude of the porosity value because density has an important role in determining thermal conductivity LFC.

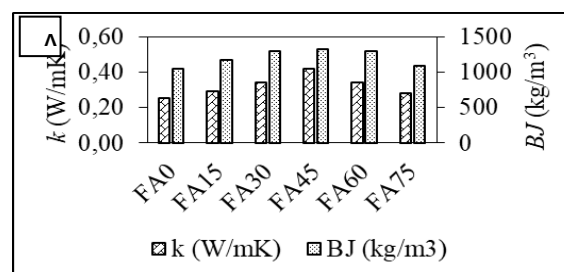


Figure 3. The thermal conductivity to density of LFC. (A) 30vol% of foam.

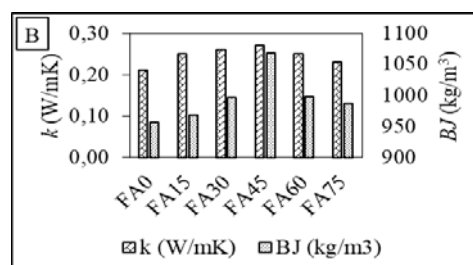


Figure 4. The thermal conductivity to density of LFC. (B) 40vol% of foam.

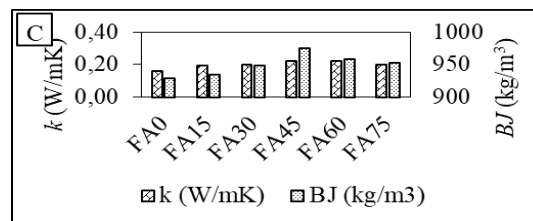


Figure 5. The thermal conductivity to density of LFC. (C) 50vol% of foam.

3.4. The morphology of LFC surface

The reaction of LFC pozzolanic consisting of fly ash will improve the lightweight concrete structure and increase the optimum compressive strength until 45% fly ash content and compressive strength decrease on the fly ash of 60%. This is because the SiO_2 (silica quartz) content in the LFC with fly ash 45% is larger than the 30% or 60% fly ash where SiO_2 belongs to a high-hardness component. The previous research has suggested that fly ash reactions in lightweight concrete will improve structures and increase a compressive strength [12]. The LFC compressive strength due to the improvement of structure optimally reaches up to 45% fly ash content and the role is decreased at 60% fly ash content.

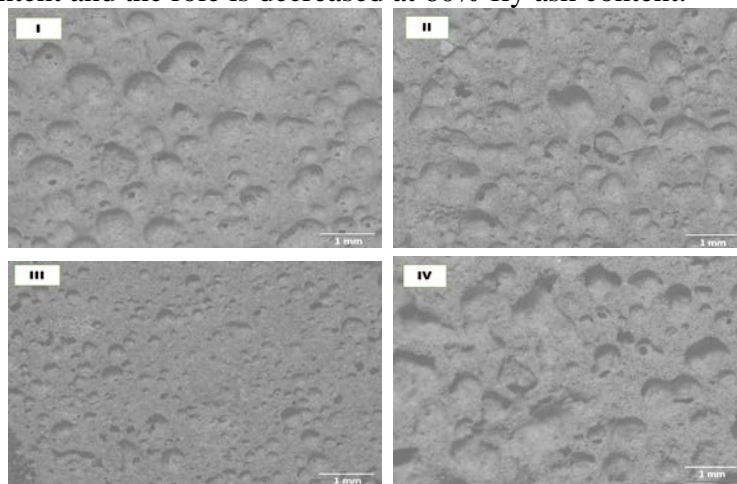


Figure 4. The micro images of Foam 30vol%. (I) 15%, (II) 30%, (III) 45% and (IV) 60% of fly ash.

The results of Energy Dispersive X-ray Spectroscopy (EDX) test as shown in Table 3 are reinforced by microscopic photographs that LFC with 45% fly ash have more air cavities with smaller size compared to LFC with 30% and 60% fly ash (Figure 4). In general, the smaller size of LFC pore will increase the compressive strength [20]. The research of Azmi's stated that a higher number and larger size of air cavity in the lightweight concrete will result in the decrease of the compressive strength (Azmi et al., 2016) and the strength of fly ash lightweight concrete is influenced by the size, proportion, and texture of the surface of fly ash particles and different sand aggregates. Smaller fly ash particles (0.01 - 0.015 mm) will fill the larger cavities between sand aggregates (4.75 mm) until achieving the optimum limit [10].

4. Conclusions

According the relationship between thermal conductivity and volume fraction of foam evidence that the increase in volume fraction of foam in all variations of FA content shows a

decrease in thermal conductivity. The highest thermal insulation is produced by LFC with the lowest thermal conductivity i.e. FA0 at 50vol% of foam. While the lowest thermal insulation was produced by LFC with the highest thermal conductivity i.e. FA45 at 30vol% of foam. The FA0 at 50vol% and FA45 at 30vol% was resulted thermal conductivity at 0.16 W/mK and 0.42 W/mK, respectively. The relationship between thermal conductivity and weight fraction of FA shows that the increase of FA content in LFC resulted in an increase in thermal conductivity weight fraction of 45wt%, then decrease as the addition of FA. Thus, the optimum thermal conductivity of the LFC was obtained by FA of 45wt%. The highest thermal conductivity at 30vol% of foam was produced by FA45 at 0.42 W/mK. The 40vol% of foam was produced the highest thermal conductivity at FA45 of 0.27 W/mK. While the 50vol% of foam was produced the highest thermal conductivity in FA composition of FA45 and FA60 at 0.22 W/mK. The relationship between thermal conductivity and LFC density shows that any increase in LFC density resulted in an increase in thermal conductivity. In contrary, any decrease in LFC density resulted in a decrease in thermal conductivity.

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