Physical, mechanical and thermal properties of lightweight foamed concrete with fly ash

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\textbf{Abstract}. This study aims to investigate the effect of fly ash content on the density, thermal conductivity, compressive strength and water absorption of Lightweight Foamed Concrete (LFC). This LFC consists of cement, water, sand, fly ash (FA) and foam. The foam is needed to create air voids in the mixture and reduce its weight. The foaming agent which was diluted in the water was given air pressure using foam generator to produce foam. The LFC are made with water-cement ratio of 1:1 and cement-agregat ratio of 1: 4. Aggregates consisted of sand and FA varied by 0\%, 10\%, 20\% and 30\% in weight. The content of foam was 30\% and 40\% of the mortar volume. The increasing of foam content decreases density, thermal conductivity, and compressive strength of LFC. However, that increases its water absorption. The increasing of FA content also decreases water absorption, but it density, thermal conductivity and compressive strength.

\textbf{1.Introduction}
Normal weight concrete (NWC) is one of preferred building materials for wall structure component which has several advantages, such as low price, high compressive strength, good weather resistance and formability. Its density is about 2,400 kg/m\textsuperscript{3} and its strength proper for building structure. While the non-structural components require building materials with low density, it can reduce the load of structures and construction costs [1].

Lightweight concrete (low density concrete) can be made with cement/mild-aggregate or cement/sand-aggregate/foam. Cement, sand and foam aggregates are known as lightweight foamed concrete (LFC), which has main composition of cement, foam, and with or without filler. Its density is 300 – 1,800 kg/m\textsuperscript{3} and affected by foam content in the lightweight concrete mix [2]. The higher the percentage of foam in the lightweight concrete, the lower of the density [3]. The lower of density results in lower the compressive strength and thermal conductivity [4]. LFC can be produced by addition of pre-foam into mortar to produce LFC without filler or LFC with filler, such as fly ash (FA), palm oil fuel ash, and clay. FA is one of the materials that can act as pozzolan to produce light concrete [5]. FA contains high calcium,
silica, and alumina which can be used to create geopolymers bond with good strength and resistance characteristics [6].

FA waste utilization for LFC is an effort to create a sustainable environment and give positive effect that has better properties, more economical for non-structural components and reduce total self-weight compared with conventional materials[7]. The LFC has excellent thermal resistance compared to NWC and other conventional materials. LFC produces better energy efficiency for use as non-structural alternative materials in tropical climates [8]. Thermal insulation materials play an important role in reducing power requirements and greenhouse gas emissions.

Those studies show that LFC has low density and thermal conductivity. LFC with FA can increase more significant in strength compared to LFC with sand. However, the density, thermal conductivity, compressive strength and water absorption of LFC with variation of fly ash percentage are not yet known. Therefore, a study to measure the effect of FA percentage on the density, the thermal conductivity, the compressive strength, and the LFC water absorption is necessary. Furthermore, the relationship between density to thermal conductivity, compressive strength, and water absorption can be obtained.

2. Experimental methods
2.1. Materials
The density of LFC was designed at 850 – 1,500 kg/m³. The LFC samples are made with constant water-cement ratio of 1:1 and cement-agregat ratio of 1:4. The sand aggregates were sieved for maximum size of 4.75mm. They consist of sand with FA addition which was varied in 0%, 10%, 20% and 30% in weight. The foam content in LFC is 30% and 40% of the mortar volume.

2.2. Samples preparation
The density, compressive strength and water absorption tests consist of 4 samples for each LFC composition with a size of 75 mm in diameter and 150 mm in height. However, the thermal conductivity test consists of 3 samples for each composition with a size of 40 mm in diameter and 8 mm in height. The composition of each sample is shown in Table 1.

| Sample code | Foam (vol%) | Cement (kg) | Sand (kg) | FA (kg) | Water (ltr) | Foam (ltr) |
|-------------|-------------|-------------|-----------|---------|-------------|------------|
| FA0         | 30          | 12,59       | 50,36     | 0,00    | 12,59       | 2,08       |
| FA10        | 30          | 12,59       | 50,36     | 5,04    | 12,59       | 2,08       |
| FA20        | 30          | 12,59       | 50,36     | 10,07   | 12,59       | 2,08       |
| FA30        | 30          | 12,59       | 50,36     | 15,11   | 12,59       | 2,08       |
| FA0         | 40          | 23,38       | 93,52     | 0,00    | 23,38       | 4,84       |
| FA10        | 40          | 23,38       | 93,52     | 9,35    | 23,38       | 4,84       |
| FA20        | 40          | 23,38       | 93,52     | 18,70   | 23,38       | 4,84       |
| FA30        | 40          | 23,38       | 93,52     | 28,06   | 23,38       | 4,84       |

2.3. Curing of LFC samples
The curing period is an important factor in the production of high mechanical strength LFC [9]. The LFC curing was in accordance with ASTM C459-99a and it was demolded after a
The next curing was performed indoors at room temperature of 21±5.5 °C for 24 days and continued with curing for 3 days in an oven at the temperature of 60±2.8 °C. The sample test was performed for the LFC after the curing age of 28 days and the LFC temperature was equal to room temperature.

2.4. Test methods
The density test of LFC was performed by weighting of sample and measuring of its mass. Then, the compressive test was conducted using a universal testing machine (UTM). The data obtained in this testing was maximum load and dimension of each sample. The thermal conductivity test was conducted using the apparatus of HVS-40-200SE model from Tokyo Meter Co. Ltd. The thermal conductivity formulae are shown in Eq. 3. Where \( k \) is thermal conductivity (W/mK), \( q \) is the heat flow (J/s), \( r \) is the sample thickness (m), \( A \) is the specimen surface area (m²) and \( \Delta T \) is the temperature difference between the hot and the cold plates (°C).

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k = \frac{q \cdot L}{A \cdot \Delta T}
\]

The water absorption test procedure was performed in accordance with ASTM C642. The water absorption formulae are shown in Eq. 2. Where \( W_A \) is the water absorption (%), \( W_s \) is the Saturated Surface Dry (SSD) mass of the test specimen in the air after immersion (g); \( W_d \) is the Open Dry (OD) mass of test specimen in the air (g).

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W_A = \frac{W_s - W_d}{W_d} \times 100
\]

3. Results and discussions
3.1. The density and the compressive strength

The increase of foam content decrease of density and compressive strength [1] due to an increase of air cavities trapped within the LFC. Mydin said that the density and compressive
strength of LWC is influenced by the amount of foam added to the mixture [2]. The results show the lowest density is 855.57 kg/m$^3$ and the highest density is at 1,524.34 kg/m$^3$. The density has good correlation with the previous research, where the LFC density was 600-1,800 kg/m$^3$ [11], [12].

The increase of FA percentage in LFC results in an increase of density and compressive strength. It is influenced by the smaller FA diameter (0.01 - 0.015 mm) compared to the sand. Smaller FA diameters tend to fill the larger diameter sand cavities (1 - 4.75 mm). This result is strengthened by previous studies that the density and compressive strength of LFC was influenced by the number and size of cavities. The pozzolanic reaction of FA improves the structure and strength of LFC [13], [14]. The FA, as an LFC additive, produces a uniform air void spread, preventing bubbles from joining one bubble with another bubble and providing a uniform membrane on each bubble. The pozzolanic reactions such as cement with fly ash and calcium hydroxide will form calcium silicate hydrates that produce small pores that increase the density and compressive strength of LFC [15].

3.2. The density and the thermal conductivity

The thermal conductivity of a material is the quantity of heat transmitted through a unit thickness in a direction perpendicular to a surface of unit area, due to a unit temperature gradient under given conditions [16]. The increase of the foam content in the LFC results in a decrease in thermal conductivity. The decrease was caused by the increase of air cavities inside the LFC which is a bad conductor compared to solid and liquid. Previous studies of LFC have shown that good heat insulation capability is obtained from the increase in closed cavities to form multi-cellular structures present in lightweight concrete [12].

![Figure 2. Density and Thermal conductivity.](image)

The density plays an important role in thermal conductivity. Any increase in FA percentage results in the increase of the density and thermal conductivity (Fig. 2). In contrast, any decrease in the LFC density results in a decrease in the thermal conductivity. A low LFC density will result in low thermal conductivity as well. The number and size of the air cavity are significant in affecting the density as it determines the thermal conductivity [15], [17].
3.3. The density and the water absorption

LFC has a higher water absorption capability compared to Normal weight Concrete (NWC) due to lower density. The higher foam content of LFC results in higher water absorption caused by the interconnection of more cell structures. Increasing the number of interconnections of these cell structures results in channels for higher water absorption. Water absorption increases with the increase in the air cavity contents and the interconnected pore structure [18].

![Figure 3. Density and Water absorption.](image)

Fig. 3 shows the influence of the density to the water absorption. Any increase in FA percentage results in an increase in the density and results in a decrease in the water absorption. In contrast, any decrease in the LFC density results in an increase in the water absorption. The results are in accordance with the previous study that water absorption increases with the decrease in the LFC density [19], [20].

4. Conclusions

The addition of foam content into the LFC results in the decrease of the density, the thermal conductivity, and the compressive strength. However, the addition of foam content into the LFC increases the water absorption. The addition of FA percentage into the LFC results in the increase of the density, the thermal conductivity, and the compressive strength. However, the addition of FA percentage content into the LFC decreases the water absorption. Higher density results in the increase of the thermal conductivity and the compressive strength. In contrast, higher density results in the decrease of the water absorption.

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