The insulation properties of foam concrete with the use of foam-agent and fly-ash

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Abstract. Foam concrete is an alternative wall material that can be used in tropical buildings because of its insulation properties, good thermal conductivity, and sound absorption coefficient when compared with the normal concrete. The percentage of foam agent used in its production affects density and compressive strength. Furthermore, the use of fly-ash also has an effect on its mechanical and insulation properties. In this study, 40 units of foam concrete specimen (200x200x20) mm were tested for thermal conductivity, and cylinder (dia-100x20) mm for sound absorption. The mixture used for the concrete includes cement/sand ratio of 1:2.75 with w/c 0.425 and addition of 20% fly-ash as a cementitious material and foaming agent (ratio fa/w 1:20) at 1%, 2%, 3% and 4% by weight of cement paste, respectively. The result showed that foam concrete with 20% fly-ash and 2% foaming agent or more has a density below 2000 kg/m3 with a maximum compressive strength of 13.24 MPa. The highest sound absorption coefficient was obtained to be $\alpha = 0.89$ at 20% fly-ash and 4% foaming agent. The thermal conductivity (k) of foam concrete was found to have increased using a 20% fly-ash and 1% foaming agent compared to the mixture without fly-ash at a value of 0.898. It was discovered that the use of fly-ash on foam concrete has the ability to improve thermal conductivity and sound absorption.

1. Introduction
Passive energy-saving houses and buildings made of thermally insulating materials have become popular in recent construction practices in order to address the demanding energy needs and reduce the consumption of hydrocarbon energy resources. Material technology is growing rapidly in the field of construction, including the use of wall materials in constructing buildings in the tropics. The use of lightweight, strong and insulating materials is now common because they provide comfort to residents and of those widely offered in tropical buildings is the foam concrete. It is a mixture of cement, water, and colophony foaming composition and a type of porous concrete with a highly workable low-density material with the ability to incorporate up to 50% entrained air. The concrete is generally self-leveling, self-compacting and can be pumped. It is made through blending, molding, maintaining, and hardening processes. The foamed concrete has the properties of porousness, lightweight, heat preservation, heat...
insulation, and sound absorption. Furthermore, fly ash foamed concrete can be produced from fly ash, lime, gypsum, and foaming composition. The material can be used to reserve heat in exterior protected construction. Foam concrete is formed from the surfactant reaction which produces air bubbles which are actually beneficial for heat transfer and sound absorption on the wall. The concrete can usually be applied to a wall panel, light concrete brick, ready mix, and special shape. However, concrete wall panels are a type of membrane panel with maximum sound-absorbing ability and curve peaks at a frequency of 250 Hz.

Several treatments have been conducted on foam concrete in order to improve insulation properties such as making pore cells closed on the concrete, giving high temperatures, and lightweight aggregate replacement but the foaming agent and fly-ash have never been applied as cementitious materials in its production.

Therefore, the aim of this study was to determine the effect of fly-ash on the insulating properties of foam concrete. The thermal conductivity was measured by heat transferability of the concrete based on the constituting materials, porosity, the temperature of the surroundings, and the direction of heat current (see Figure 1)

Figure 1. Diagram of air voids in foam concrete

2. Literature review
Foamed concrete, which is also known as a closed-cell structure, is one of the materials in the lightweight category. It has a low density between 300 kg/m$^3$ to 1600 kg/m$^3$ and thermal conductivity properties between 0.10 W/m.K to 0.66 W/m.K. It was discovered that its structure plays important roles in providing great thermal insulation performance [1].

A study had been conducted to quantify the thermal properties of lightweight foamed concrete (LFC) at high temperatures with a density of 600 to 1800 kg/m$^3$ [2]. This was aimed at obtaining data to predict fire resistance of LFC based systems. The concrete is considered to be a two-phase material with solid cement and air pores, therefore, there is an assumption that its thermal conductivity is a function of its porosity and pore size. The temperature on LFC was found to be increasing its heat conductivity. A concrete with a density of 650 kg/m$^3$ has lower thermal conductivity (average $k = 0.3$ W/m.$^\circ$C) compared to the one with 1000 kg/m$^3$ (average $k = 0.2$ W/m.$^\circ$C), however, both will experience a decrease in their thermal conductivity until the temperature approaches 200$^\circ$C to 1000$^\circ$C where it continues to increase. It is, however, important to state that these predictions are moderately affected by the air pore diameter, hence, the size of the pore should be determined with good accuracy. For LFC densities of 650 kg/m$^3$ and 1000 kg/m$^3$, the average pore diameter may be taken as 0.72 mm and 0.55 mm respectively.

The replacement of normal aggregate with lightweight ones effectively reduces the thermal conductivity depending on the raw materials used. The hollow glass bubble also causes a reduction in thermal conductivity but its impact is less pronounced compared to coarse aggregates. Studies conducted by Yun, Tae Sup et al [3] explained that the most effective insulating additive to achieve a thermal conductivity of $\sim$1.25 W/m.K is through the addition of 20–30% of glass bubbles as well as the
replacement of cement by fly-ash and incorporation of a water-reducing agent on the thermal insulation and mechanical properties of porous concrete with a density of 600 kg/m^3 [4]. It was found that porous concrete achieved optimum performance with a water-binder ratio of 0.32, a fly ash replacement percentage of 30% and the addition of 0.65% of the water-reducing agent. Under these optimal conditions, 28-day compressive strength up to 4.37 MPa, 12% rate of water absorption, and a thermal conductivity coefficient of 0.116 W/mK were observed in the specimen obtained.

A state of the art research has been conducted on the insulation properties of foam concrete and it has been discovered that covering cell pores in concrete, providing high heat to reduce the coefficient of thermal conductivity, replacing aggregates with hollow glass bubbles, and cement with fly-ash and water reducing-agent have the ability of producing the lowest conductivity coefficient of 0.116 W/mK.

3. Materials and method
In this study, 40 units of (200x200x20) mm and (dia-100x20) mm concrete foam with a mixture of cement/sand at 1:2.75, w/c 0.425 and 20% fly-ash by weight of cement were used as specimen (Table 1). Foaming agent was also added with a ratio of 1:20 (fa/w) both without fly-ash and with fly-ash at 1%, 2%, 3% and 4% of the weight of the cement. Tests were conducted after 28 days of production with reference to ASTM C1044-98 (The Hot-Guarded-Plate Test) and ASTM C384-98 (Impedance Tube Method), for sound absorption test set-up (see Figure 2). The sound absorption test on the specimen was measured with a sound level meter device with respect to the frequency of the sources 250, 500, 1000 and 2000 Hz. In general, the steps of this research are shown in Figure 3.

Table 1. Mix-proportion of specimen

| Materials                          | Mix-controls | Mix-proportion |
|-----------------------------------|--------------|----------------|
|                                   | I  |   II   | III   | IV   | I   |   II   | III   | IV   |
| cement                            | 1  | 1.1   | 1.1   | 1.1  | 0.8 | 0.8    | 0.8    | 0.8  |
| fly-ash/cement ratio              | -  |   -    |   -   |   -  | 0.2 | 0.2    | 0.2    | 0.2  |
| sand                              | 2.75 | 2.75  | 2.75  | 2.75 | 2.75| 2.75   | 2.75   | 2.75 |
| water/cement ratio                | 0.425 | 0.425 | 0.425 | 0.425| 0.425| 0.425  | 0.425  | 0.425 |
| Percentage of foaming-agent by cement weight (%) | 1  | 2     | 3     | 4    | 1   | 2      | 3      | 4    |

Figure Caption.
1. Impedance Tube
2. Specimen
3. Sound Level meter
4. Power amplifier
5. Data processing

Figure 2. The experimental stand used for the sound absorption coefficient measurement
4. Results and discussions

4.1. Strength and density

The density of the foam concrete is influenced by the quantity of foaming agent and fly-ash used such that the more foaming agent produced, the smaller the density (Figure 4). While the use of a 20% fly-ash tends to produce larger density, concrete produced from a 4% foaming agent without using fly-ash has the lowest density of 1560 kg/m$^3$. It was found that using this material from the range of 2% of the weight of cement has the ability to produce concrete in the lightweight due to the value of its density < 2000 kg/m$^3$.

Furthermore, the largest compressive strength was obtained with the use of a 2% foaming agent, 13 MPa without fly-ash and 13.24 MPa with a 20% fly-ash. The complete test results can be seen in Table 2.

![Figure 4. Strength and density of foam concrete](image-url)
Table 2. Properties of foam concrete

| Foam agent | Density (kg/m³) | Compressive strength, 28 days (MPa) | Thermal conductivity (W/m.K) |
|------------|-----------------|-------------------------------------|-----------------------------|
|            | No fly-ash | 20% Fly-ash | No fly-ash | 20% Fly-ash | No fly-ash | 20% Fly-ash |
| 1%         | 2031       | 2031       | 10.08     | 10.48      | 0.838     | 0.898      |
| 2%         | 1825       | 1853       | 13.00     | 13.24      | 0.898     | 0.896      |
| 3%         | 1666       | 1766       | 10.22     | 10.62      | 0.894     | 0.893      |
| 4%         | 1560       | 1585       | 7.96      | 8.36       | 0.885     | 0.886      |

Nambiar and Ramamurthy [5] reported that foam concrete density ranged from 400 - 1600 kg/m³. Furthermore, Cement Ready Mix, one of the ready-mix companies in Mexico, classified foam concrete produced based on its density value, with the Highly Air-Entrained Concrete (HAC) type ranging between 1600 - 2000 kg/m³. According to SNI 03-2847-2002, the density of lightweight concrete should not be more than 1900 kg/m³.

The replacement of cement by an appropriate amount of fly ash has the ability to favorably reduce the overall cost of the end product. At an early curing age (7 days), the strength of the porous concrete decreased significantly with an increase in the fly ash content and at a later curing age (28 days), it can be enhanced when more fly ash is added. It has also been found that the compressive strength at 28-day curing would be up to 4.14 MPa when 30% of cement has been replaced by the fly ash [4].

A different case was observed in the research conducted by Kozłowski and Kadela [6] where the foam concrete without fly-ash seemed to show higher strength than the mixtures containing fly-ash. This can be attributed to the slowing down of the hardening process because of the presence of fly-ash. The compressive strength and modulus of elasticity were also slightly decreased by the addition of 5% fly ash.

4.2. Thermal conductivity

Materials with high thermal conductivity are good conductors, while those with low thermal conductivity are good heat-insulating materials. The addition of fly-ash to the foam concrete is expected to improve the insulating properties of the foam material. However, pores are formed due to the use of foam agents in the production process to increase the thermal conductivity value of the foam concrete while the use of fly-ash as cementitious only serves to increase adhesion between aggregate and bubbles formed in the concrete matrix.

The air bubbles formed by mixing a foaming agent in the foam-making process affect the heat delivery mechanism through the formation of pores. However, the dominant fly ash grains will fill the pores because their functions are inversely proportional to those of the foaming agents. This is important because the factors affecting the value of thermal conductivity include the type of aggregate and porosity (pore type, volume, spacing, direction, and moisture). The pore volume produced by the foaming agent is not too different from the one produced through the use of fly-ash to increase the adhesiveness between the surface of the aggregate.

In Figure 5, the use of fly-ash in concrete foam does not have any significant effect on the value of thermal conductivity. It was also discovered that increasing the percentage of the foaming agent above 2% does not also have any significant effect. Whereas in conventional concrete or mortar, the usage of 20% fly-ash as cementitious increases the value of thermal conductivity. Therefore, production of foam concrete with the use of foaming agent and 20% cementitious fly ash have better thermal conductivity properties compared with ordinary concrete (k = 1.448 W/m.K) and this is evident from the 0.898, 0.896, 0.893, and 0.886 W/m.K obtained on each use of 1%, 2%, 3%, and 4% foaming agent.
Figure 6 shows the relationship between thermal conductivity and density based on the quantity of foaming agent and 20% cementitious fly-ash. It was found that the use of fly-ash does not significantly affect the density of the foam concrete material but very influential in lowering the thermal conductivity when a 1% foaming agent is used in the manufacturing process.

### 4.3. Sound absorption

The sound absorption coefficient of foam concrete specimens with average was measured at a peak frequency of 2000 Hz with an increase of 100 Hz intervals as shown in Table 3.

![Figure 5. Thermal conductivity of foaming-agent](image)

![Figure 6. Density and thermal conductivity of foam concrete](image)

**Table 3. Sound absorption of foam concrete**

| Specimen                  | Foaming agent | Sound absorption coefficient ($\alpha$) |
|----------------------------|---------------|----------------------------------------|
|                            |               | Frequency measurement (Hz) Average      |
|                            |               | 250 | 500 | 1000 | 2000 |                |
| Foam concrete without fly-ash | 1%            | 0.72 | 0.57 | 0.85 | 0.55 | 0.67          |
|                            | 2%            | 0.78 | 0.67 | 0.90 | 0.65 | 0.75          |
Figure 7 shows the relationship between the sound absorption coefficient with the addition of the foaming agent and the cementitious fly-ash. The graph shows that the continuous use of a foaming agent increases the sound absorption coefficient. This can be attributed to the addition of more air bubbles to the concrete mix through the inclusion of the material in the production process because a large number of concrete pores formed results in better sound insulation for the concrete. This is similar to a study conducted on three treatments including coarse, smooth, and painted surfaces by Zulfian et al. [7]. The aim was to create a porous surface in order to increase sound absorption value and the coefficient obtained for the rough surface at the lowest frequency of 125 was 0.33, it can significantly increase in its sound absorption coefficient compared to others.

The use of fly-ash as a cementitious material produces better sound absorption compared to those without fly-ash. However, the rate is determined by the quantity of foaming agent used. The highest value of 0.89 was obtained with a 20% fly-ash and a 4% foaming agent.

5. Conclusion
The use of 20% fly-ash as cementitious material and 2% foaming agent has the ability to produce foam concrete with densities lesser than 2000 kg/m$^3$ and optimum compressive strength of 13.24 MPa. It was also discovered that 20% fly-ash did not have any significant effect on thermal conductivity (k) of foam concrete, however, the value of k decreased with the addition of foaming agent with the lowest being 0.838 at 1% without fly-ash. Furthermore, sound absorption ($\alpha$) increased with the use of a 20% fly-ash and peaked to $\alpha_{\text{maximum}}$ 0.89 through the use of a 4% foaming agent.

Acknowledgment
The authors would like to express their sincere gratitude to The Directorate Research and Community of Services, The Directorate General of Strengthening Research and Development, and The Ministry of Research, Technology, and Higher Education, Indonesia for financing this research.
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