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Utilization of palm oil fuel ash (POFA) in producing lightweight foamed concrete for non-structural building material

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Abstract

The utilization of the materials from the industrial waste is an option to reduce the production cost of building materials that also will reduce the environmental impact from the waste. Industrial by-product from the palm oil mill in the form of palm oil fuel ash (POFA) can be used as a partial replacement for cement into the concrete mix due to its pozzolanic content. This study examines the role of POFA to replace the cement partially in foamed concrete production. Experiments have been conducted by replacing 10%, 20%, 30%, 40% and 50% of POFA by weight of Portland Pozzolan Cement. The results indicate a potential use of POFA in foamed concrete production. Despite a decline in the strength of concrete with the addition of POFA, the loss of concrete compressive strength by adding 50% POFA is only about 30-40% compared to that of control specimens. Based on its compressive strength, the foamed concrete with 20% POFA substitution is still applicable for non-structural building element such as concrete block for non-bearing wall. Indonesia as the largest palm oil industry produce a large amount of POFA that can be potentially utilized to produce low cost lightweight building material and also to reduce the environmental impact as well.

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1. Introduction

The main building material used in Indonesia is concrete applied for various building elements, both for structural and non-structural, as well as for architectural elements. Concrete has several advantages such as easy to set up, high

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compressive strength, adjustable quality, and locally available material. However, concrete also has disadvantage in terms of its weight. This is a major disadvantage when it is applied to earthquake prone areas like Indonesia. Lightweight foamed concrete is an alternative building material to reduce the risk of building damage due to earthquake disaster.

Lightweight foamed concrete is made by introducing air through the proprietary foam process to control the density of the concrete. The density of foamed concrete range from 300 to 1800 kg/m³, which is significantly lower than that of normal concrete (2400 kg/m³). Foamed concrete can be composed only by cement, water, and foam. It may also contain lightweight aggregate, fine aggregate or agricultural/industrial waste as a filler. The use of agricultural waste materials in concrete are intensively studied recently [1-2]. Some of industrial/agricultural waste have been utilized in concrete are rice husk ash [3-4], bagasse ash [5], and palm oil waste [6-9]. Besides as the filler, some industrial or agricultural waste materials can also replace the role of cement as the binder of concrete due to high silica content in its chemical properties. One the industrial by-product that can be used in foamed concrete is the waste of the palm oil industry in form of palm oil fuel ash (POFA). The combustion process of palm oil husk and palm kernel shell in the steam boiler produces POFA [10].

POFA can be used as constituents in concrete due to the pozzolanic properties. Many researchers have studied the use of POFA in normal concrete [6,11-12], high strength concrete [7,13], and lightweight concrete, including foamed concrete [14-16]. The studies has revealed that agricultural waste ashes contained high amount of silica and could be used as a pozzolanic material. POFA is one of the agro waste ashes whose chemical composition contains a large amount of silica and potentially used as a cement replacement [17]. Due to high silica oxide content in POFA which met the pozzolanic properties criteria, it is potentially utilized as cement replacement or as filler to produce strong and durable concrete [18].

This study focuses on developing the lighter density of foamed concrete (the density below 1.0) to be applied for non-structural building elements. To reduce the production cost of the lightweight foamed concrete, the industrial by-products (POFA) are utilized in the concrete mix. The POFA partially replace the cementitious material. The mechanical behaviors of the concrete containing POFA were investigated. The foamed concrete specimens were casted to measure the compressive and tensile strength of the concrete for different content of POFA. The density of foamed concrete specimens is controlled at 1000 and 800 kg/m³ varied by 10%, 20%, 30%, 40%, and 50% of POFA. The percentage of POFA is based on the weight of cement to partially replace the cement. The potential replacement and the characteristics of lightweight foamed concrete containing the POFA are discussed in this paper.

2. Experimental

2.1. Materials

The lightweight foamed concrete with POFA consist of four types of raw material, namely Portland Pozzoland Cement, POFA, water, and foam. It does not contain coarse and fine aggregates. Foamed concrete is produced by adding pre-formed foam to mortar mass. The amount of the foam controls the density of foamed concrete.

Portland Pozzolan Cement (PPC) Type I from a single source was used throughout the experimental programs. The physical and chemical properties of PPC were not examined in this study since the material has been certified for Indonesian Standard (SNI) 03-2847-2002. However, physical inspection conducted on the condition of the packaging and condition of the cement grains which are still in a good condition.

Foam is in a form of bubbles produced by mixing the foam agent and water using a foam generator. The foam controls the density of lightweight foamed concrete by incorporating pre-formed foam into fresh concrete mix. For this study, the ratio of foaming agent to water is 1:30 by the volume.

Water is one of the most important constituents for hydration process to produce concrete. The water used should not contain any substance as the presence of any other substance can be harmful to the process of hydration of cement and durability of concrete. The drinking water from city supply were used in the experiments.

2.2. Palm oil fuel ash (POFA)

POFA is a solid waste by-product of palm oil industry obtained in the form of ash from the burning of palm oil husk and palm kernel shell used as fuel in palm oil mill steam boiler. The POFA used throughout this study was collected from a local palm oil mill located in Tamiang, Province of Aceh. The collected ashes were dried for 24 hours before sieved and then immersed to the water for separation of incomplete burned material. The floated object is considered as organic material and removed from the POFA. The cleaned POFA obtained was dried in an oven at $105 \pm 5^\circ\text{C}$ for 24 hours to remove the moisture content. The dried POFA was then sieved through a 4.75 mm sieve size in order to remove the bigger size particles. The distribution of POFA grain is shown in Fig. 1. The specific gravity of POFA was measured at 1.485 kg/m^3 .

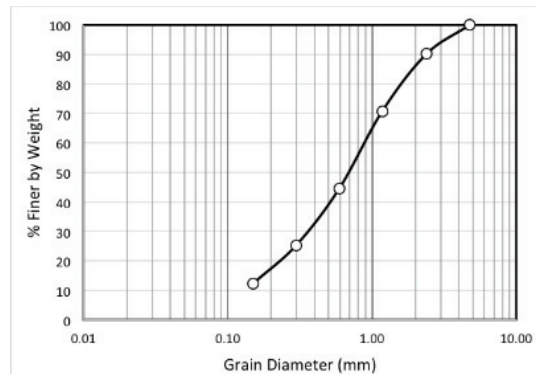


Fig. 1. The sieve size analysis of POFA used in the experiment

2.3. Foamed concrete mixtures

The mix proportion of the lightweight foamed concrete incorporated with POFA was determined by volume controlled for target density of foamed concrete based on the specific gravity of each raw material. The water/binder (cement + POFA filler) ratio was set to 0.5. The targeted density of the foamed concrete are 800 and 1000 kg/m^3 . The portion of POFA to replace cement are varied by 10%, 20%, 30%, 40% and 50% of cementitious weight. The normal foamed concrete without POFA are also casted as controlled specimens (0% of POFA). The composition of all the materials for all the foamed concrete mix for SG 0.8 and 1.0 are shown in Table 1 and Table 2, respectively.

2.4. Specimens

The specimens were casted based on proportion of the mix design shown in Table 1 and Table 2. The PPC and POFA were weighted and mixed in a concrete mixer until the dry mix was uniformly mixed, then the water was weighted and added into the dry mix. After the mortar was uniformly mixed, the volume of foam was added into the wet mix and controlled for targeted density, 800 and 1000 kg/m^3 .

The total of 120 specimens were casted to investigate the compressive and flexural tensile strength of foamed concrete incorporated with POFA, consisting of 84 cylindrical specimens ($\varnothing 10 \text{ cm} \times 20 \text{ cm}$), and 36 beam specimens ($40 \text{ cm} \times 10 \text{ cm} \times 10 \text{ cm}$). The cylindrical specimens and the beam specimens are the test samples for compressive strength and flexural tensile strength, respectively. In addition, the specimens for SG 0.5, 0.6, 0.7, and 0.9 are also casted to evaluate the relationship of compressive strength of foamed concrete with 20% and 50% POFA for various SG. All the specimens were cured by immersing into the water for 7 days and then exposed to shaded open air for the rest before the testing schedules. The compressive strength were tested for 7, 14, 28, 180, and 360 days. The flexural strength were only tested for 28 days.

Table 1. The composition for 1 m³ of foamed concrete for 800 kg/m³ of unit weight.

No	%POFA	PPC (kg)	Water (kg)	POFA (kg)	Foam (liter)
1	0%	533.33	266.67	-	564.02
2	10%	500.00	250.00	50.00	557.60
3	20%	470.59	235.29	94.12	551.94
4	30%	444.44	222.22	133.33	546.91
5	40%	421.05	210.53	168.42	542.42
6	50%	400.00	200.00	200.00	538.36

Table 2. The composition for 1 m³ of foamed concrete for 1000 kg/m³ of unit weight.

No	%POFA	PPC (kg)	Water (kg)	POFA (kg)	Foam (liter)
1	0%	666.67	333.33	-	455.03
2	10%	625.00	312.50	62.50	447.01
3	20%	588.24	294.12	117.65	439.93
4	30%	555.56	277.78	166.67	433.64
5	40%	526.32	263.16	210.53	428.02
6	50%	500.00	250.00	250.00	422.95

The compressive strength is tested using compression testing machine. The test was performed in accordance with ASTM Standard C234. An axial compressive load with a specified rate of loading was applied to Ø10 cm-20 cm until failure occurred. The flexural test was referred to ASTM-C.78-94 method by third-point loading. For each of the test, the mean value obtained from three specimens were taken as the compressive strength and flexural tensile strength for each mix.

3. Result and Discussion

3.1. Compressive strength

The compressive strength of foamed concrete at 28 days for each the SG for all proportion of POFA shown in Fig. 2(a). The compressive strength are consistently decreased by increasing of POFA content in the concrete mix. The percentage of reduction in compressive strength due to the addition of POFA in foamed concrete compared to that of the normal foamed concrete without POFA are shown in Table 3.

This results show differences from that of the research conducted by several researchers [6,12,14-15] that the addition of POFA up to 30% can improve the compressive strength of the concrete. This experiments show that the addition of POFA tends to reduce the compressive strenght of foamed concrete. However, the physical and chemical properties used in this experiment are different. The bottom ash POFA (ground ash) is used in this experiment, while most of research mentioned above used fly ash POFA. The particle size of POFA is finer for fly ash than that of the ground ash POFA. The high content of Silicon dioxide (SiO₂) in fly ash increases the chemical reaction process so that the concrete compressive strength of concrete increases. The concentration of SiO₂ in the POFA used in this research is relatively smaller than that in the studies conducted in Malaysia [14-15] and Thailand [6].

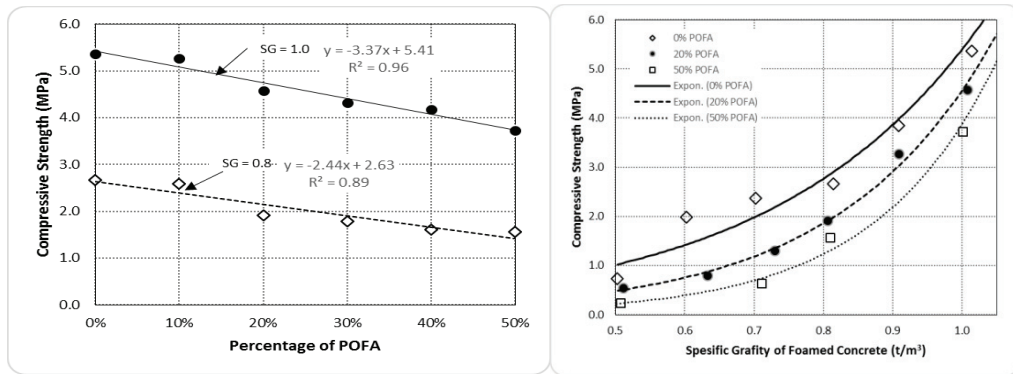


Fig. 2. (a) The compressive strength of foamed concrete with all variation of POFA for SG 0.8 and SG 1.0 and (b) the compressive strength of foamed concrete with 0%, 20%, and 50 % of POFA for all variation of SG

Fig. 2(a) shows that the compressive strength decrease linearly along with the additional of POFA. The addition of 50% of POFA yields the lowest compressive strength in average both for SG 1.0 and SG 0.8 for about 3.72 MPa and 1.40 MPa, respectively. The incorporation of POFA for 10% insignificantly decreased the compressive strength. The relationship of the compressive strength and the SG is shown in Fig. 2(a). Fig. 2(b) shows the decreasing in compressive strength with a similar tendency for all the SG.

Table 3. Percentage of decreasing in compressive and tensile strength for each SG by addition of POFA compared to that of normal foamed concrete

POFA	SG=1.0		SG=0.8	
	Compressive	Tensile	Compressive	Tensile
10%	1.85	(7.87)	3.09	7.08
20%	14.76	23.15	27.97	15.04
30%	19.60	34.26	33.09	23.01
40%	22.26	36.11	39.67	33.63
50%	30.73	44.44	41.30	47.79

3.2. Flexural tensile strength

The average values of flexural tensile strength of the all test specimens are shown in Fig. 3, which presents the change in flexural strength due to the addition of POFA in the foamed concrete. Like the compressive strength, the flexural strengths are also decreasing linearly in line with the addition of POFA for each SG. In general, the tendency of decrease in the flexural tensile strength are the same as the compressive strength. The rate of decline in flexural tensile strength due to the addition of POFA is faster for the foamed concrete with higher SG (1.0) compared to that of the lower SG (0.8).

The ratio and flexural tensile strength to the compressive strength of POFA foamed concrete are shown in Fig. 3. Tensile strength is much lower than compressive strength. As shown in Table 3, the flexural tensile strength also decrease by increasing of POFA weight in foamed concrete. Generally, the tensile strength development shared the same trend with compressive strength development. Equation 1, 2, and 3 show the relationship of the tensile and compressive strengths of the foamed concrete for 0%, 20%, and 50% of POFA, respectively.

3.3. Development of Concrete Strength

Fig. 5 shows the strength development by age of concrete in logarithmic relationship for up to 1 year of the concrete age. Similar to that of in normal concrete, the compressive strength of foamed concrete POFA increases by

the age accordingly. The rate of increase in the strength of foam concrete with POFA is slower than that of the normal concrete because the use of POFA can slow the early hardening process. The advanced development of the strength at the age of 180 and 360 days for the 20% and 50% POFA are higher than that of the normal foamed concrete (0% POFA). This results show the role of POFA in strength development of the concrete.

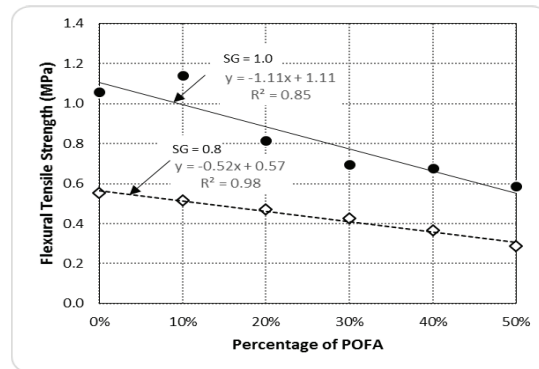


Fig. 3. The flexural tensile strength of foamed concrete with all variation of POFA for SG 0.8 and SG 1.0.

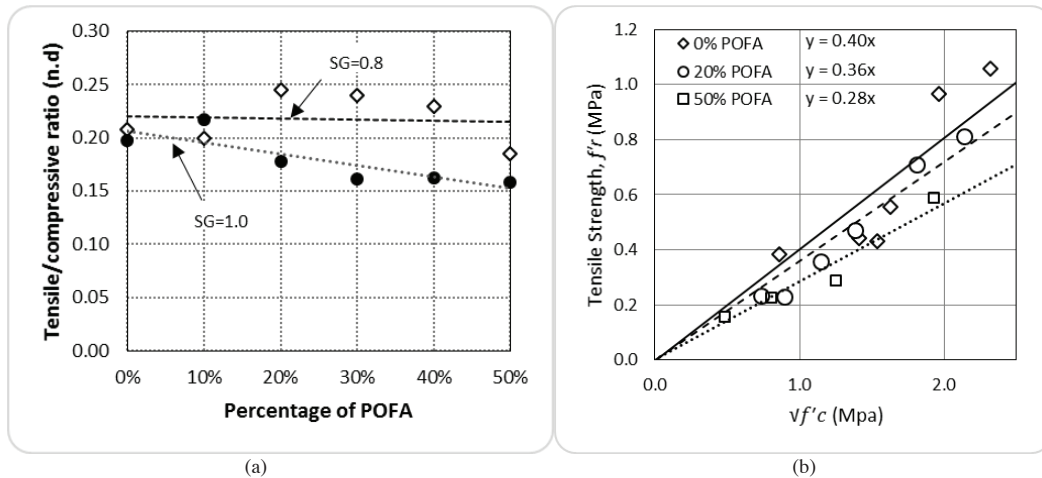


Fig. 4. (a) The ratio of tensile to compressive strength at age of 28 days of POFA foamed concrete, (b) relation of compressive and tensile strength of foamed concrete with POFA

$$f'_{tr} = 0.40\sqrt{f'_{cr}} \quad (1)$$

$$f'_{tr} = 0.36\sqrt{f'_{cr}} \quad (2)$$

$$f'_{tr} = 0.28\sqrt{f'_{cr}} \quad (3)$$

3.4. Application for non-structural components

Compressive strength of concrete is the main reference in assessing the strength of concrete achievements. The compressive strength of foamed concrete with POFA as a partial replacement of cement showed a decreasing in strength compared to the normal foamed concrete. However, the addition POFA up to 20% is still possible for non-structural applications in construction. This can be seen from the value of the average compressive strength obtained for foamed concrete with SG 0.8 which is over 2 MPa. A significant increment in compressive strength shown at 1-year of the age of the concrete, where the concrete SG 0.8 with 20% POFA have a compressive strength for more

than 3 MPa as shown in Fig. 5. The compressive strength obtained with the addition of POFA still meet the requirements for use on non-structural components, i.e. 0.35 s/d 7 MPa [19].

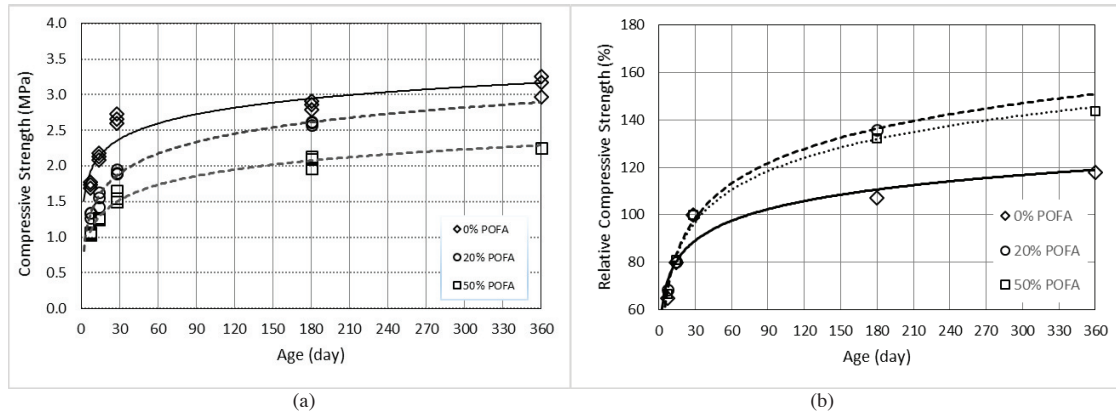


Fig. 5. The logarithmic relationship of the compressive strength and the age of POFA foamed concrete; (a) absolute value compressive strength by the age, and (b) relative strength of the concrete compared to that of standard 28 days of the age (100% of the strength at 28 day).

Foamed concrete block already used in construction for non-bearing wall to replace the role of clay brick which is not environmentally friendly. Currently, the construction industries much depend on traditional construction materials, such as clay bricks for the wall and conventional concrete for structural elements. The conventional materials are still very dependent on the natural resources. Clay brick is produced mainly from clay soil that is excavated from top soil and mostly processed traditionally using wood as fuel energy for burning in the kiln. Similarly for conventional concrete, the aggregate materials are still dependent on natural resources. Due to large-scale exploitation, the environmental impact is currently occurring as a disaster.

Incorporating the POFA into low density foamed concrete of 800 kg/m³ and 1000 kg/m³ gained the compressive of the concrete about 3-6 MPa. This value is still acceptable for non-structural components such as partition wall. Concrete block and decorative block can be made from this mixture.

4. Conclusion

The expensive price of building materials is an obstacle in the provision of low-cost housing efforts. The utilization of locally available materials and from industrial waste is an option to reduce the cost of production of building materials. The use of industrial waste as building material will also solve the problem of environmental impact. Industrial by-product from the palm oil mill in the form of palm oil fuel ash form (POFA) can be used as a partial replacement for cement in concrete mix. This study examines the role of POFA as the filler in foamed concrete in replacing cement partially in concrete production. The POFA replaces the cement up to 50% on the basis of the weight cement in this experiment. The results indicate a potential use of POFA in foamed concrete production for non-structural building material. Despite a decline in the strength of concrete with the addition of POFA, the loss of concrete compressive strength by adding 50% POFA is only about 30~40%. The addition of 20% POFA yields the acceptable strength of foamed concrete for non-structural purposes. The decrease of compressive strength is insignificant in terms of economic value by cement replacement. Indonesia as the largest palm oil industry produces a large amount of POFA that can potentially be utilized to produce low cost lightweight building material.

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