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WORKABILITY AND STRENGTH PERFORMANCE OF FOAMED PALM OIL WASTE CONCRETE

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ABSTRACT

Palm oil industry is one of the most promising and rapidly growing industries Malaysia. However, lots of by-products are generated such as palm oil clinker (POC) and palm oil fuel ash (POFA) which end up being dumped and left untreated in dumping area which results in environmental pollution. With the increasing amount of palm oil wastes generated annually, incorporation of POC and POFA in concrete production can provide a good solution to overcome this problem. The currents research investigates the effect of palm oil fuel ash when added as partial cement replacement towards workability, density and strength performance of palm oil clinker foamed concrete. A total of six mixes were used in this experimental work. Palm oil clinker concrete produced using 100% ordinary Portland cement were considered as control specimen. The rest of the mixes contain POFA as partial cement replacement 10%, 20%, 30%, 40% and 50%. All specimens are produced in 100 x 100 mm cubes and is subjected to water curing before subjected to compressive test on 7 and 28 days. The finding shows that workability of concrete decreases when the amount of POFA added is increased. In terms of strength performance, foamed concrete containing 10% of POFA exhibit the highest compressive strength of all specimens.

Keywords-foamed palm oil clinker concrete, palm oil fuel ash, workability, density, compressive strength

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INTRODUCTION

Concrete is regarded as one of the most common construction material nowadays. With rapid growth in construction globally, the demand for concrete is increasing day by-days. Hence, large amounts of raw materials and natural resources are required in order to meet the industry's demand. These results in negative impact to the environment as well as contribute to depletion of natural aggregate resources for future purposes. Concrete industry consumes about 8 to 12 million tons of natural aggregate annually, after 2010 (Tu et al., 2006). According to Hamid et al. (2006), insufficient supply of aggregates will lead to an increase in construction cost and then transferring the burden to end users and eventually affecting the national development. High demand of aggregate for concrete production requires high amount of natural aggregates which will destroy the ecological balance of the environment. Hence, an action need to be taken in order to reduce the dependency of concrete industry on natural aggregate. In addition, development in construction industries have increased the concrete demand and is expected by 2020, global demand for cement would increase by 115 – 180% compared to the 1990s (Damtoft et al., 2008). Concrete industry results in carbon dioxide (CO_2) emission during its manufacturing process, and high production of concrete will lead to high emission of CO_2 into the atmosphere. According to Malhotra (2000), cement industry produced about 7% of all CO_2 generated worldwide. According to Aprianti et al. (2015) concrete is non-friendly material and is not suitable for sustainable development due to several issues such as high energy and aggregate consumption, demolition waste of concrete and filler requirements which contributed to environmental impact. Hence, incorporation of waste materials from industries in concrete production as aggregate or cement replacement would not only reduce the dependency of natural aggregates, reduce amount of waste disposed in landfill and at the same time reduce construction cost and produce more environmental-friendly materials.

At the same time, palm oil industry as one of the main contributor to Malaysia's economy is producing a large amount of palm oil wastes that contribute to environmental pollution. Palm oil clinker (POC) and palm oil fuel ash (POFA) are both by-products obtained from the incineration process of oil palm shell and mesocarp fiber. Physically, POC are porous, grey in colour, flaky, irregular in shape and lighter compared to natural aggregate (Mohammed et al., 2011). According to Kanadasan and Abdul Razak (2015), POC is usually landfilled in plantation areas or used as a cover for potholes on roads in estate area. POFA is a greyish form of ash and becomes darker as the proportions of unburned carbon increase (Aprianti et al., 2015). Malaysian Palm Oil Berhad (2011) reported that about 3 million tons of POFA were produced in 2011. POFA usually dumped in open field near palm oil mills without any profitable return, causing environmental pollution and health hazards (Tonnayopas et al., 2006). As stated by Foo and Hameed (1990) common disposal methods were conducted without considering the surrounding environment or taking precaution action to compact, cover and prevent the spreading of pollutants into the ground water level. Moreover, due to its fine particles, POFA can be easily carried away by the wind and can cause smog on a humid day (Tay, 1990). The negative impact of this waste towards environment has been highlighted by previous researchers, Muthusamy and Zamri (2016) and Ismail et al. (2010) who investigated the possibility of using this waste in concrete production. Incorporation of these by-products as construction materials is considered as a practical approach in reducing the amount of waste in landfill areas and provide a cleaner environment for the future. In order to solve of the problems related to natural aggregate issues, pollution by cement industries and palm oil industry wastes, the current research investigates the possibility of using palm oil fuel ash as partial cement replacement in foamed palm oil clinker concrete production. The paper discusses the workability, density and strength performance of foamed palm oil clinker containing palm oil fuel ash at various percentages.

EXPERIMENTAL PROCEDURE

A. Materials

Foamed concrete is produced by mixing slurry mortar with foaming agent. The slurry mortar contains cement, fine aggregate and water in certain proportion. Ordinary Portland cement (OPC) complying to MS 522: Part 1: 2003 was used throughout this study. Normal tap water was used for mixing, which is suitable for concreting works in accordance to BS 3148: 1980. A hydrolyzed protein foaming agent was used to produce foamed concrete since it is widely available in the market. According to McGovern (2000), protein based foaming agent produced smaller bubbles and the bonding structures of the bubbles are stronger and more stable compared to synthetic based foaming agent. Both solid wastes, palm oil clinker (POC) and palm oil fuel ash were collected from a palm oil fruit processing factory in Lepar Hilir, Pahang. Figure 1 and Figure 2 show POC dumping area and the collecting process respectively. Collected POC were cleaned with tap water and oven-dried for 24 hours. Large chunks of POC were grounded into required size and

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POC passing 1.18 mm sieve were used as fine aggregates. Similar to POC, POFA were oven-dried for 24 hours prior to use in order to remove its excessive moisture. POFA were then ground to be fine enough fulfilling the requirement in ASTM C 618 (2015) enabling it to be used as partial cement replacement. Fig. 3 and Fig. 4 illustrate POFA dumping area and sieved POFA respectively. Based on the chemical composition tabulated in Table 1, the collected POFA is classified as pozzolanic material Class C,in compliance with ASTM C618 (2015).

Figure 1: Palm oil clinker dumping area

Figure 2: Collecting palm oil clinker

Figure 3: Palm oil fuel ash dumping area

Figure 4: Sieved POFA

Table 1: Chemical composition of OPC dan POFA

Constituents	OPC	POFA
Silicon dioxide (SiO_2)	16.05	51.55
Aluminium oxide (Al_2O_3)	3.41	4.64
Iron (III) oxide (Fe_2O_3)	3.41	8.64
Calcium oxide (CaO)	62.28	5.91
Magnesium oxide (MgO)	0.56	2.44
Sodium oxide (Na_2O)	0.06	0.07
Potassium oxide (K_2O)	0.82	5.50

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Sulfur trioxide (SO_3)	4.10	0.61
Loss of ignition (LOI)	1.2	5

B. Mix Proportioning and Testing Methods

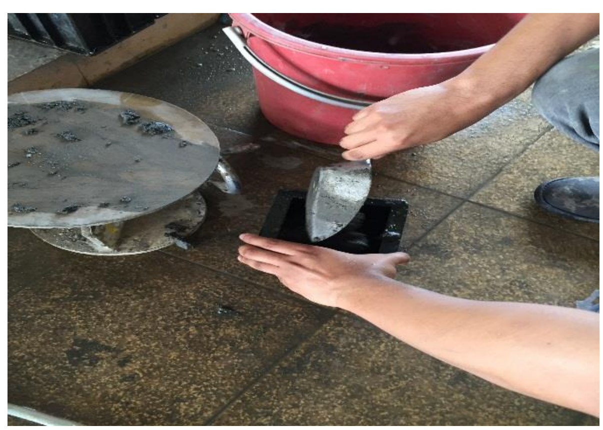
This study was conducted by using different percentages of POFA as partial cement replacement. The percentage of POFA used as cement replacement are 0%, 10%, 20%, 30%, 40% and 50% of the weight of total cementitious material. 18 samples of 100 x 100mm cubes were prepared in this study and all specimens were subjected to water curing for 28 days. Fresh and hardened properties of concrete such as workability, compressive strength and dry density were measured. Flow table test which complies to ASTM C 1437 (2007) was conducted to determine foamed concrete workability. The spread diameter values were measured to evaluate the flowability and consistency of the fresh foamed concrete mix. Figure 5, 6, 7 and 8 showed the process involved during foamed concrete fabrication. All specimens were subjected to compressive strength test complies to BS EN 12390-3 (2002) after 28 days. As for dry density, weight of specimens were measured after oven-dried for 24 hours after 28 days.

Figure 5: Foamed concrete mixing

Figure 6: Mixture of foamed concrete

Figure 7: Measuring concrete workability

Figure 8: Pouring concrete into mould



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RESULTS AND DISCUSSION

Figure 9 shows the result of flow of POC foamed concrete containing different percentages of POFA. Control specimen has the highest flow compared to POC foamed concrete containing POFA. Generally, addition of this ash as partial cement replacement reduces the concrete workability. It can be seen that flow of concrete decrease when the amount of POFA is increased. This probably due to grinding effect that increases the surface area POFA leading to reduction in concrete workability. This trend obtained in this testing is similarly as reported by other researchers (Abdul Awal, 1998; Muthusamy et al., 2015 and Alsubari et al, 2014) who has investigated the effect of POFA on the types of concrete and found that inclusion of POFA as partial cement replacement causes reduction in the workability of mix.

As can be observed in Figure 10, the utilization of this agricultural by-product affect this lightweight concrete density. It can be observed that integration of larger amount of POFA causes increment in the dry density of concrete. When POFA is added, concrete mix started to experience reduction in workability as the water is absorbed by fine POFA. As a result, concrete paste will become more viscous and causing the dry density of concrete is increased. As the amount of POFA integrated in the mix is increased, it is observed that the concrete mix become stickier which causing its dry density increases. This explains why control specimen has the lowest dry density while POC foamed concrete with 50% of POFA score the highest. Addition of 10% of POFA results in satisfactory workability which in required range between 200 – 230 mm. In this study, although incorporation of POFA managed to produce foamed concrete with density below 1800 kg/m^3, addition of 10% of POFA seem to be the best solution by considering the workability aspect. In conclusion, addition of 10% of POFA managed to produce concrete that fulfilled the workability and density requirement.

The experimental work conducted also discovers that use of suitable content of POFA contributes towards strength enhancement of concrete as can be observed in Figure 11. Addition of 10% of POFA as partial cement replacement increases the strength of foamed palm oil clinker concrete with compressive strength at 28 days reached the highest at 18.08 MPa as compared to all mixes. Addition of POFA exceedings 10% decreases the compressive strength of foamed concrete whereby as more POFA is used, the lower the compressive strength value is observed for the mix. It is observed that integration of 40% and 50% results in significant strength reduction. Although addition of POFA would enhance the strength of concrete, replacement of POFA at high level would reduced its compressive strength. Incorporation of POFA which is a pozzolanic material will trigger a pozzolanic reaction that reacts with calcium hydroxide ($Ca(OH)_2$ which is a by-product from hydration process to form secondary C-S-H gel. Formation of C-S-H gel would fill in the voids in concrete structure, resulting in a denser concrete with enhancement in concrete strength and workability respectively. However, addition of too much amount of POFA will reduce the cement content and results in reduction of the amount of calcium oxide (CaO) which is essential for hydration process to occur. Less amount of CaO would generate less amount of $Ca(OH)_2$ which is needed for pozzolanic reaction to occur. The similar trends also noted by past researchers such as Hussin et al. (2008), Hadi et al. (2015), Muthusamy (2009) and Zamri (2014).

Figure 9: Flow of POC foamed concrete containing different percentages of POFA

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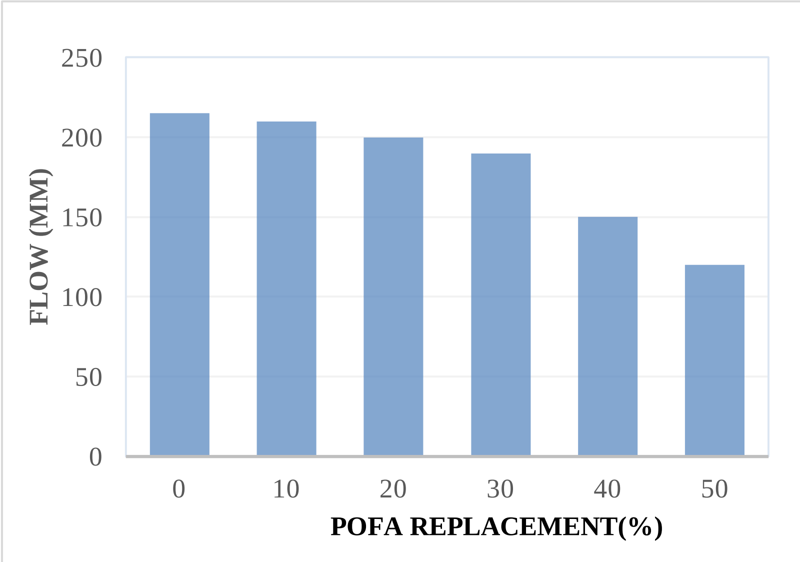

Figure 10: Dry density of POC foamed concrete containing different percentages of POFA

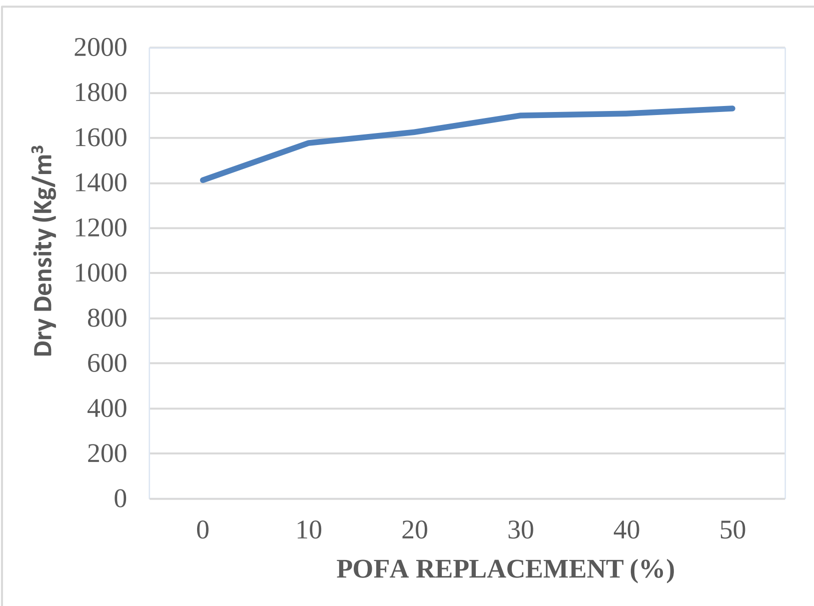

Figure 11: Compressive strength of foamed palm oil clinker concrete containing different percentages of palm oil fuel ash at 28 days

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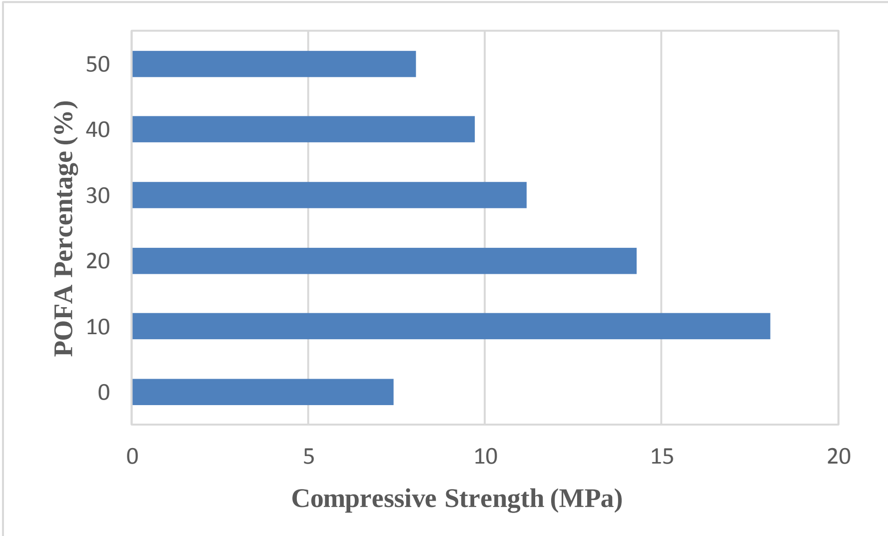

4. CONCLUSION

In conclusion, addition of POFA in POC foamed concrete production affects its fresh and hardened properties. Workability of POC foamed concrete decrease as the amount of POFA added is increased. Incorporation of POFA also influence the dry density of POC foamed concrete. The dry density of foamed concrete increases as amount of POFA used become higher. Inclusion of 10% of POFA enhances the compressive strength of foamed palm oil clinker concrete compared to control specimen. Production of foamed concrete containing high amount of palm oil waste is one of the solution to decrease the amount of palm oil wastes dumped as environmentally polluting waste, promotes towards lesser use of cement as well as creating a better environment for future generation.

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