Effect on consistency and performance of POFA concrete

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Abstract. This paper presents the experimental investigation conducted on Grade 30 concrete incorporating agro-industrial waste, Palm Oil Fuel Ash (POFA). The emergence of palm oil industry also creates other problem in waste management to our country. POFA was detected with high silica-alumina, being utilized as pozzolan which makes it as a good binding media similar to cement. In this paper, the specimens consist of 45 concrete cube size 100 x 100 x 100 mm at 3 different replacement level which were 0% as control specimen, 5% and 10% with two different techniques form which were powder and liquidation technique. The workability of fresh concrete properties was evaluated using slump test and flow table test and the performance of the hardened concrete was confirmed by cube compressive strength test at 3, 7 and 28 days. Based on the result, 5% POFA replacement using liquidation technique showed more workability compared to 10% POFA replacement. This phenomenon is due to the liquidation at POFA that acts as a liquid lubricant which can easily blend with cement component. However, concrete with 5% POFA using powder technique gives better result on the concrete performance. Powder technique shows better enhancement in strength as compared to liquid is due to the interaction between the raw POFA that’s creates better bonding as compared to the POFA which was filled with water in liquid forms.

1. Introduction

Concrete is man-made construction material that has been used widely in the world and become second important substance after water [1]. For the country and society to be developed, concrete has been used to construct roads, bridge, railways and tunnels and not forgetting the buildings. It is essential as a main anchor in providing better economic and social for humans in this world [2]. Concrete is a material created by combining cement, water, fine and coarse aggregates. Portland cement, which is one of the most important materials in concrete mix proportion, is very expensive and the price is keep increased throughout the year. The productions of cement also contribute emission of carbon dioxide (CO2) to the air. Previous study stated that 10 billion tonnes of gravel, sand and crushed rock and 1.6 billion tonnes of Portland cements are being yearned to make concrete every year globally and that seven percent of the all global emission of carbon dioxide was elucidated by the yearly production of cement [3]. The mineral admixtures were increasingly utilized by the concrete and cement industries [4]. The rising demand pattern for concrete and cement may be made possible with the introduction of cement replacement. In terms of durability and workability, valid improvements were significantly found from the presence of those mineral admixtures in concrete. The adoption of silica fume, fly ash, palm oil fuel ash, quarry dust, rice husk ash and other similar pozzolanic material as alternatives for cement replacement have been used in the past few decades. The primary causes such as technological, economical, ecological issues contribute the growing interest in using waste materials in construction industry [5]. Therefore, it is essential to look into other raw material that inexpensive and yet sustainable as partial cement replacement. Apart from fly ash, silica fume and rice husk ash that have been used widely used in replacing cement, new method to
improve concrete properties has been studied recently which is using palm oil fuel ash (POFA). The usage of POFA in concrete can be an alternative yet valuable usage of these by-product materials in construction building material industry by replacing it in concrete production as cement replacement material, other than using it for agriculture purpose. POFA is produced from the burning of palm oil wastes such as shell, fiber and empty fruit bunches as a fuel to heat the steam for palm oil extraction process. Ismail et al. [6] states that POFA is one of the agro waste ashes whose chemical composition contains a large amount of silica and that has high potential to be used as a cement replacement. The usage of POFA as partial cement replacement can cause reduction in cost of concrete production which gives great advantages to construction industry in planning construction projects with much cheaper cost [6, 7]. Thus, the utilization of POFA as partial cement replacement can reduce the environmental problems, preventing health risk to human and producing economical concrete. The objectives of this study were to determine the workability of Grade 30 concrete containing POFA as partial cement replacement of 5% and 10% cement replacement by using powder and liquidation techniques and to evaluate the performance of Grade 30 concrete with POFA as Supplementary Cementitious Materials of 5% and 10% cement replacement by using powder and liquidation techniques.

2. Materials and Method

In this study, POFA was obtained at a Palm Oil Factory in Nibong Tebal, Pulau Pinang and the study used POFA with the particle size of 212 µm. The concrete were designed for Grade 30 with constant w/b of 0.54. POFA was use as partial cement replacement with 5% and 10% cement replacements using different liquidation and powder technique. Slump and flow table test were conducted for fresh properties to anlyze on the workability mixes. Nine cubes of 100 x 100 x 100 mm size were produced, which designed to evaluate on its performance by performing on compressive strength test at day 3, 7 and 28 age of testing. Then, the result was compared with control specimen which is Ordinary Portland Cement (OPC) and also to find the most efficiently percentage and technique to replacing POFA in cement. The castings of the concrete, fresh and hardened testing test were conduct at Concrete Laboratory, UiTM Cawangan Pulau Pinang. Table 1 shows the mix proportion for this study. Mix designation 5PP indicated 5% POFA using powder technique whilst 10PP indicated 10% POFA using the same technique. For POFA liquidation technique, the designation used were 5PL and 10PL. The difference between both designations were cement replacement level with POFA, 5% and 10%.

Table 1. Concrete mix proportion

| Mix Designation | Cement (kg/m³) | POFA (kg/m³) | Water (kg/m³) | Fine aggregate (kg/m³) | Coarse aggregate (kg/m³) |
|-----------------|----------------|-------------|---------------|------------------------|--------------------------|
| OPC             | 380            | -           | 205           | 680                    | 1155                     |
| 5PP             | 360            | 20          | 205           | 680                    | 1155                     |
| 5PL             | 360            | 20          | 205           | 680                    | 1155                     |
| (41 – mix with POFA) |               |             |               |                        |                          |
| 10PP            | 340            | 40          | 205           | 680                    | 1155                     |
| 10PL            | 340            | 40          | 205           | 680                    | 1155                     |
| (41 – mix with POFA) |               |             |               |                        |                          |

2.1 Liquidation technique

The steps for mixing POFA concrete was same with normal concrete. The only difference was POFA preparation before the mixing process. POFA in powder form being diluted with water through certain
ratio before being mixed together with other ingredients in making concrete. The ratio is 1kg of water required in concrete mix: 200ml of water need to dilute the POFA powder (1kg water: 200ml for dilution). For this concrete mix, water required is 1.845kg then the water for dilute with the POFA is 369ml.

2.2 Powder technique
POFA in powder form being mixed together with cement powder before the concrete mixing. Furthermore, the calculation of selected percentage which are 5% and 10%, same to the liquidation technique by replacing the cement partially with the POFA. The selected percentage of POFA are 5% and 10%. In this powder technique does not need water to dilute the POFA powder before mixing.

3. Result and discussion
For this study the discussion of the findings separated into two. First, effect to the workability for fresh concrete and second effect to the performance of hardened concrete. The result and discussion are as follows.

3.1. Effect of POFA on workability

Figure 1. Result of workability

According to result presented in Figure 1 above, the heights of slump are decreasing as the content or amount of POFA that replaced with cement increased. Also, the type of slump are shear slump which indicates that the concrete lacks of cohesion. The result of slump test for 5% liquidation of POFA are 154 mm and its shows the highest value compared others replacement of POFA. The result of lowest slump test is at 68 mm which marked by 10% powder replacement of POFA. Based on the result, liquidation technique provides better workability to the concrete as compared to powder form of POFA and also to the OPC. However, increase the level of POFA for both technique, workability of concrete also showing a decreasing pattern. This behavior has been reported which described that POFA concrete show the highest workability than other pozzolans and the workability shows a crucial reduction when the quantities of replacing cement content increased [8]. The reduction in slump of the effect on powder method of mixing POFA can be clearly seen in this study due to the concrete mix produced was not stiff when it reacts with POFA compare to liquidation technique. In addition, the reduction in slump was due to the absorption of some quantity of mixing water by the by-product particles [9]. More water molecules are attracting to the surface particles, due to this large surface of this agriculture waste product. As a result, it decreased the amount of the free water that is available

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for the concrete mix, and it also helps the fluidity of the mixture to be improved. In addition, the viscosity of the concrete mix increasing and it turn to the reducing the height in the slump test.

The similar pattern was observed in flow table test. The optimum replacement for POFA to maintain its freshness and consistency is marked at 5% and both technique performs a similar improvement in flowability of concrete as compared to the 10% replacement and OPC. This phenomenon is due to the liquidation at POFA that acts as a liquid lubricant which can easily blend with cement component. In other words, the dilution process of liquid POFA is better than powder POFA in order to achieve a good and consistent concrete.

3.2. Effect of POFA on performance

Figure 2. Result of performance

Figure 2 shows the effect of POFA on compressive strength at 3, 7 and 28 day of ages. At day 3, the inclusion of POFA in concrete either as powder or liquid improves the compressive strength of concrete. The highest compressive strength is achieved by PP5 which inclusion of 5% POFA using powder, followed by PL5, PP10, PL10 and OPC at 27 MPa, 22 MPa, 21 MPa, 17 MPa and 16 MPa respectively. It shows that POFA enhance the concrete strength at early ages and this is expected due to filler effect of POFA which in micro based filler to densifying the surface of concrete and refining the pores that can be refines by OPC. The strength increment for concrete with the inclusion of POFA was extended to day 7. The same behavior of strength enhancement at day 3 can be seen at day 7. At day 7 the highest strength were recorded by PP5 and followed by PL5, PP10, PL10 and OPC recorded the lowest compressive strength. At this age, the enhancement of strength performs by POFA was created by the initial pozzolanic reaction form the particles of POFA and creates additional hydration product with cement. This action will increase the numbers of hydration product and also binding media in concrete and resulting in strength improvement. Finally at day 28, concrete with powder technique at 5% replacement recorded the optimum compressive strength as compared to liquid technique at every replacement level and also OPC. At this age the possible explanation that can be concluded, that the formation of pozzolanic reaction is already completed and the strength enhancement from POFA from the effect of silica and alumina well tailored in cement particles. The highest compressive strength recorded is 42 MPa and performs by PP5 mix. In addition, from this findings shows that the strength of compressive strength with partial replacement of POFA by using powder technique is higher than liquidation technique. The reason can be due to the slow pozzolanic activity of the POFA [10]. Moreover, the adhesion mechanisms between CSH and POFA as fillers
affect a great significance when it employed as a cement replacement. Affinity of POFA as filler found chemically inert, however, even if they have several hydraulic properties or if they enter a harmless reaction with the products of reaction in the hydrated cement paste, it has no disadvantage [11]. In this study, POFA have sieve into 212 mm, which finer as compared to the raw POFA. This can produce a good packing effect, fine fillers that present inside the concrete can effect in improvements in strength [12]. Also, fineness of POFA, which helps the reaction with Ca(OH)$_2$ to produce an additional calcium silicate hydrate, which improves the compressive strength of concrete. Finally, powder technique shows better enhancement in strength as compared to liquid is due to the interaction between the raw POFA that’s creates better bonding as compared to the POFA which was filled with water in liquid forms. Although, in liquid forms, the consistency is better, but in performance due to excessive water will slow down the pozzolanic reaction of POFA and strength is expected to be slow as compared to the powder forms.

4. Conclusions
The main objective of this study was successfully achieved. Some conclusions can be as listed below:

1. The result of slump test for 5% liquidation of POFA shows the highest value compared others replacement of POFA. Liquidation technique provides better consistency to the concrete as compared to powder form of POFA and also to the OPC. It can be concluded that the workability of partial replacement of POFA in concrete was satisfactory and within the range that expected in the slump range.
2. The optimum POFA replacement in concrete is marked at 5% and both techniques perform a similar improvement in flowability of concrete as compared to the 10% replacement and OPC.
3. The compressive strength with 5% partial replacement of POFA with powder technique shows highest result compare to others and this can be the optimal percentage and the best technique use for the replacement of POFA in concrete. Powder technique shows better enhancement in strength as compared to liquidation technique.

Recommendations were stated for improvement of the study so that future researchers can refer to this study to achieve better results and findings:

1. The amount percentage of POFA between 1% to 5%, 6% to 10% and 10% upward need to be studied so that the strength of concrete decrease as the amount of POFA increase can be proved.
2. The optimum percentage of POFA replacing cement also can be discovered, use the higher fineness of POFA for the study because it had been proved by some researchers that the high fineness of POFA increase the strength of concrete and increase the curing age of specimen to investigate the performance of the concrete of certain desired curing age.

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