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A Comparative Study on Utilization of Palm Oil Fuel Ash (POFA) as Partial Cement Replacement in Concrete

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Abstract: Palm oil industry is extremely important agricultural and economic sector in Malaysia. Despite the apparent benefits, the palm oil industry also produces abundance of waste such as palm empty fruit bunches, palm trunk and palm kernel which causes a problem on environmental degradation. Palm oil fuel ash (POFA) is one of waste materials obtained during burning process of palm oil waste that can be utilized as alternative construction materials in concrete. This study was reviewed the utilization of POFA as partial cement replacement in concrete. Based on previous studies, the effects of POFA on workability, compressive strength of concrete containing different percentages of POFA was presented. Accordingly, the optimum percentage of POFA as partial cement replacement in concrete can be determined. Many studies have shown that the utilization of POFA as partial cement replacement in range of 5% to 40% can produce better workability, durability and compressive strength of concrete than concrete containing Ordinary Portland Cement only. Besides, the replacement of cement with POFA significantly reducing carbon emissions then improving environmental degradation issues.

Keywords: Concrete, Palm Oil Fuel Ash, POFA

1. Introduction

Concrete is one of the building construction material that commonly used. It is made of cement, coarse aggregates, fine aggregates, and blended in with water, which strengthen with time. Concrete used for foundations, columns, beams, slabs and other load-bearing elements in the construction firm. However, concrete material manufacturing can harm the environment, especially in producing cement. The Portland cement manufacturing industry emitted large volume of CO_2 and SO_2 to the atmosphere [1]. These types of gases can cause air pollution and "greenhouse" effect [2]. The usage of cement in the making of concrete can be reduced by partially substitute with other substances such as palm oil fuel ash (POFA).

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Palm oil industry in Malaysia has expand to become a primary agricultural sector over the last few decades, that makes the country currently the world's top palm oil producer and exporter [3]. Palm oil is Malaysia's most compelling fruits which has helped transform its agricultural and economic scenario. Although it had obvious advantages, the palm oil industries also lead to environmental pollution, both on the start and end of its operations. For example, consequential supplies of water and energy are used when palm oil process started at palm oil mills. The mills also generate significant quantities of industrial waste, wastewater and air pollution at the palm oil process ends. POFA, empty fruit bunches, mesocarp fruit fibres, and palm kernel shell are the waste that commonly generated by the palm oil mills [4]. Every year, 10 million tons of POFA is produced in Malaysia [5]. The existing POFA are eventually in desperate need to be beneficially used.

This study was carried out to overcome the problem of unused agricultural waste of POFA. The process of cement production at the plant also leads indirectly to environment deterioration. Moreover, due to the increase cost of raw materials, the cost of cement is keep increasing. So, the utilization of POFA as cement replacement in concrete can reduce environmental pollution problems and manufacturing cost of cement. The results of this study could provide an alternative to the use of cement for the manufacture of construction materials. So, the objectives of this study are to identify the workability and compressive strength performance of concrete containing POFA and to determine the optimum percentage of POFA as partial cement replacement in concrete.

2. Palm Oil Fuel Ash (POFA)

POFA is one of the wastes produced by the palm oil mill. This waste was produced by the combustion of palm oil residue to provide electricity for the palm oil mill [6]. Tangchirapat and Jaturapitakkul [7] stated that only a few amounts of POFA that had been utilized as the only used of POFA is only for fertilizers and backfilling. The unused POFA will precipitate environmental issues as it will be disposed at landfills as waste. Over 1000 tons of palm oil waste have been left out into landfills and lagoons in Malaysia without being utilized [8]. It can cause environmental problem when POFA disposed in open areas [6].

2.1 Physical Properties of POFA

Hamada et al. [5] has conducted a review on the POFA's physical properties. The author stated that the burning temperature and other conditions can affect POFA's physical properties. The author observed that in natural condition, POFA colour is grey. However, if the POFA contains high concentrations of unburned carbon it becomes darker. Then after more combustion, the carbon is eliminated and the colour switch back to grey [10]. POFA's specific gravity is lower than the specific gravity of cement, which ranged between 2.6 and 1.89.

2.2 Chemical Composition of POFA

Hamada et al. [5] has done a review on the POFA's chemical composition. The author had documented a wide range of experimental projects, due to major variations in the conditions such as combustion temperature, the amounts POFA derived from palm oil from different plants and other influences. Concrete hydration heat [11], compressive strength and workability is determined by the chemical properties of materials. The use of waste material as a cement replacement was a significant success, as its chemical composition leads to supplying tremendous quality concrete in line with stringent environmental laws. [12]. Hamada et al. [5] mentioned that POFA's key composition is silicone dioxide (SiO_2) that ranges from 43% to 71% and it can help produces high quality concrete with POFA's strong pozzolanic properties.

3. Methodology

The review analysis involved two experiment results such as workability and compressive strength. About 35 research papers had been reviewed which were all of the papers covered on the compressive strength of concrete that contains POFA. Meanwhile, out of 35 paper, 22 papers covered on the workability. Accordingly, the optimum percentage of POFA as cement replacement in concrete were obtained from previous studies. All the papers were listed in Table 1 and Table 2 according to the performance of concrete by using POFA.

Table 1: Previous studies on workability of concrete by using POFA

Author	Product	Optimum Percentage (%)	Workability (mm)
Zeyad et al. [13]	High Strength Concrete	40	**225**
Jaturapitakkul et al. [14]	Concrete	40	**80**
Muthusamy et al. [15]	Lightweight Concrete	10	**96**
Ahmad et al. [16]	Concrete	5	**170**
Sidek et al. [17]	Concrete	5	**148**
Tambichik et al. [9]	Concrete	10	**35**
Oyejobi [18]	Concrete	10	**35**
Rosseli et al. [19]	Concrete	5	**154**
Sata, Jaturapitakkul and Kiattikomol [20]	High Strength Concrete	10	**200**
Vanchai, Chai and Kraiwood [21]	High Strength Concrete	10	**200**
Sanawung et al. [22]	Concrete	25	**80**
Zeyad et al. [12]	High Strength Concrete	60	**230**
Awal & Abubakar [23]	Concrete	50	**140**
Johari et al. [24]	High Strength Concrete	60	**230**
Mohamad et al. [25]	Concrete	2	**63**
Islam et al. [26]	Lightweight concrete	10	**65**
Islam et al. [27]	Lightweight concrete	30	**30**
Hassan et al. [28]	High Strength Concrete	10	**100**
Tangchirapat and Jaturapitakkul [7]	Concrete	20	**60**
Tangchirapat, Khamklai & Jaturapitakkul [29]	Lightweight concrete	20	**80**
Tangchirapat, Jaturapitakkul & Chindaprasirt [30]	High Strength Concrete	10	**250**
Tangchirapat et al. [31]	Concrete	40	**80**

Table 2: Previous studies on compressive strength of concrete by using POFA

Author	**Product**	**Optimum Percentage (%)**	**Compressive Strength (MPa) (28 days curing)**
Zeyad et al. [13]	High Strength Concrete	40	**103**
Razali et al. [32]	Concrete	2.5	**42.8**
Aiswarya et al. [33]	Concrete	10	**43.1**
Jaturapitakkul et al. [14]	Concrete	10	**24.5**
Yahaya et al. [34]	High Strength Concrete	20	**68.8**
Shehu & Awal [35]	Concrete	50	**35**
Muthusamy & Zamri [36]	Lightweight Concrete	20	**35**
Muthusamy et al. [15]	High Strength Concrete	10	**64**
Subhashini & Krishnamoorthi [37]	Concrete	20	**36.4**
Sofri et al. [38]	Concrete	10	**47.7**
Ahmad et al. [16]	Concrete	15	**48**
Sidek et al. [17]	Concrete	5	**40.6**
Tambichik et al. [9]	Concrete	10	**32.4**
Manap et al. [39]	Concrete	20	**25.4**
Oyejobi [18]	Concrete	10	**24**
Rosseli et al. [19]	Concrete	5	**40**
Tasnim et al. [40]	Concrete	10	**52**
Ahamed & Siddiraju [41]	Concrete	12.5	**34.3**
Sata et al. [20]	High Strength Concrete	20	**85**
Vanchai et al. [21]	High Strength Concrete	20	**85.9**
Sanawung et al. [22]	Concrete	15	**46.2**
Zeyad et al. [12]	High Strength Concrete	40	**101.5**
Awal & Abubakar [23]	Concrete	50	**28**
Hamada et al. [42]	High Strength Concrete	10	**64.8**
Johari et al. [24]	High Strength Concrete	40	**105**
Mohamad et al. [25]	Concrete	6	**38.6**
Islam et al. [26]	Lightweight Concrete	10	**42.4**
Islam et al. [27]	Lightweight Concrete	10	**41**
Chindaprasirt et al. [43]	Concrete	20	**23.9**
Vanchai et al. [44]	Concrete	20	**49**
Hassan et al. [28]	High Strength Concrete	10	**63.3**
Tangchirapat & Jaturapitakkul [7]	Concrete	10	**41**
Tangchirapat, Khamklai & Jaturapitakkul [29]	Lightweight concrete	20	**28**
Tangchirapat, Jaturapitakkul & Chindaprasirt [30]	High Strength Concrete	20	**60.9**
Tangchirapat et al. [31]	Concrete	10	**23**

4. Analysis on Workability Performance

Figure 1 shows the workability against the optimum percentage of POFA as cement replacement in normal concrete (NC), high strength concrete (HSC) and lightweight concrete (LWC). From the Figure 1, the highest workability of 250 mm was obtained from previous study that conducted by Tangchirapat et al. [30] that using 10% of POFA as partial replacement of cement in HSC. Moreover, most of the previous studies that utilize POFA in HSC at Figure 1 had better workability than control sample [13][12][24][30] which shows that the use of POFA can increase the workability of HSC. According to Islam et al. [27], this is happened because POFA have lower specific gravity than cement. The graph also showed that all the HSC had a higher workability performance compared to NC and LWC. This is due to the addition of additives such as superplasticizer that improve the workability of HSC.

Referring to the Figure 1, the workability of NC increased when the amount of POFA added to the concrete mix increased up to 5% of POFA as cement replacement, with the highest workability obtained by Ahmad et al. [16] about 170 mm. However, almost all of the studies that partially subtitute POFA with cement in NC samples at Figure 1 were obtained less workability than control sample [16][9][18][22][23][25][7] which shows that the use of POFA can decrease the workability of NC. According to Tambichik et al. [9], high-water absorption ability of POFA had deteriorate the workability performance of concrete.

Meanwhile, for LWC, the workability of LWC increased when the amount of POFA added to the concrete mix increased up to 10%, with the highest workability obtained by Muthusamy et al. [15] about 91 mm. Moreover, all of the previous studies that utilize POFA in LWC at Figure 1 had better workability than control sample [15][26][27][29] which shows that the use of POFA can increase the workability of LWC. According to Ahmad et al. [16], the spherical shape of pozzolans particles of POFA helps to improve the workability of LWC. But, when the percent of POFA is increased more than 10%, the workability of LWC has dropped. This caused by POFA's high specific surface that reduce the workability performance of concrete [9].

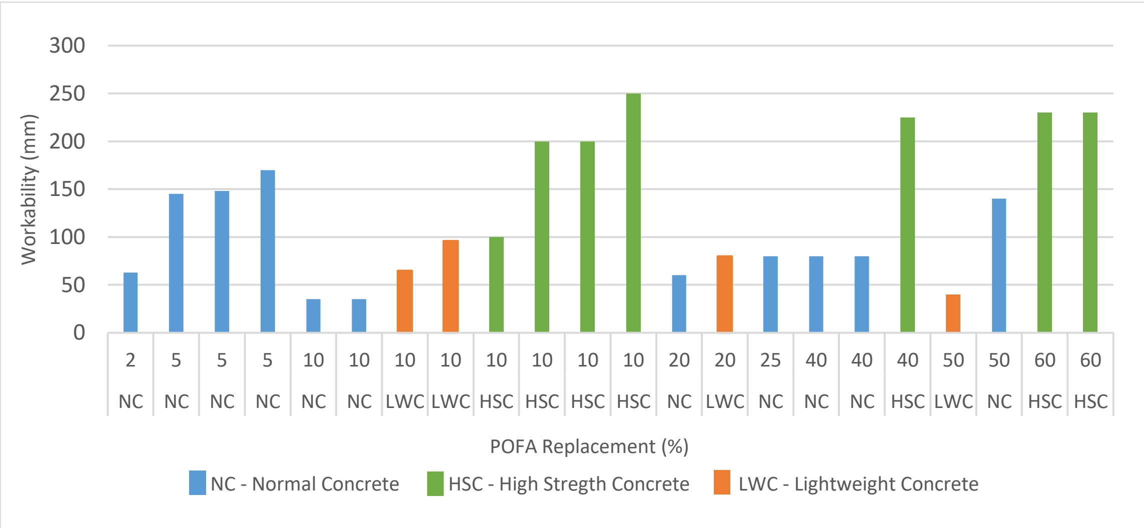

Figure 1: Workability versus optimum percentage of POFA as partial cement replacement in various types of concrete

5. Analysis on Compressive Strength Performance

Figure 2 shows the compressive strength of concrete with different optimum percentage of POFA in HSC, NC and LWC, accordance to previous research studies. As shown in Figure 2, the highest compressive strength is 105 MPa by using 40% of POFA as partial replacement of cement in HSC. Moreover, all of the previous studies that utilize POFA in HSC at Figure 2 had better compressive strength than control sample which shows that the use of POFA can increase the compressive strength of HSC. According to Johari et al. [24], this could be attributed to the pozzolanic reaction between the POFA and $Ca(OH)_2$, to produce secondary C–S–H, densifying the concrete microstructure, resulting in higher strength. The graph also showed that all HSC experienced higher compressive strength performance. This is due to the addition of additives such as superplasticizer that improve the compressive strength of the concrete.

For NC, the compressive strength of NC increased when the amount of POFA added to the concrete mix increased up to 10% of POFA as cement replacement, with the highest compressive strength obtained by Tasnim et al. [40] about 52 MPa. Moreover, most of the previous studies that utilize POFA in NC at Figure 4.2 had better compressive strength than control sample [32][33][16][17][19][40][41][44][28] which shows that the use of POFA can increase the compressive strength of NC. This is mainly due to the formation of calcium silicate hydrates (S-C-H). However, the compressive strength of NC starts to drop when the amount of POFA is increased more than 10%. This is due to voids created inside the concrete structure when the POFA is added to the mix [9].

Meanwhile, the highest compressive strength for LWC is 42 MPa by using 10% of POFA as partial replacement of cement. Moreover, all of the previous studies that utilize POFA in LWC at Figure 2 had better compressive strength than control sample which shows that the use of POFA can increase the compressive strength of LWC. Islam et al. [26] found out that this phenomenon was likely due to the presence of POFA that facilitate the conversion of the un-hydrated CH particles to CSH gels due to the pozzolanic reaction with POFA, thus improving the compressive. However, the compressive strength of LWC is dropped when the amount of POFA increased to 20%. The reduction in compressive strength is mainly due to the huge reduction in the cement content.

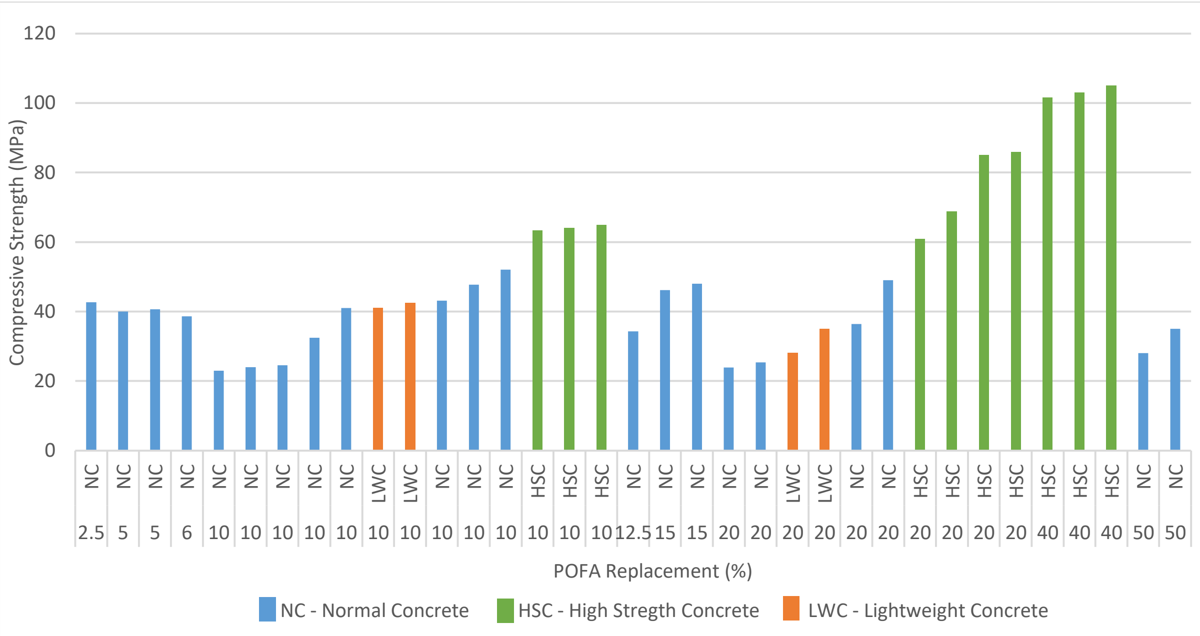

Figure 2: Compressive strength versus optimum percentage of POFA as partial cement replacement in various type of concrete

6. Conclusion

Based on the review analysis, it can be concluded that the utilization of POFA can affect the workability and compressive strength of high strength concrete (HSC) and also lightweight concrete (LWC). The improvement of workability performance is mainly due to POFA's specific gravity that is lower than cement. However, the use of POFA in normal concrete (NC) has decrease its workability due to POFA's high-water absorbtion ability. The increasing strength in concrete is could be attributed to the pozzolanic reaction between the POFA and $Ca(OH)_2$ that densifying the concrete microstructure thus resulting higher strength of concrete.

It was found that the optimum percentage of POFA as partial cement replacement in HSC and LWC is 10% to obtain better workability of concrete. In terms of compressive strength, the optimum percentage of POFA is 40% for HSC and 10% for LWC in order to obtain higher compressive strength performance of concrete.

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