International Journal of Engineering & Technology, 7 (3.23) (2018) 49-52

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Potential of Ground and Unground Palm Oil Fuel Ash in Construction Material

Faiza Roslee[1]*, Nor Amani Filzah Mohd Kamil[1], Aeslina Abd Kadir[1], Ismallianto Isia[2], Mohd Ikhmal Haqeem Hassan[1]

[1]University Tun Hussein Onn Malaysia, Johor
[2]University Teknologi Malaysia, Johor
**Corresponding author E-mail: faizaroslee@gmail.com*

Abstract

The uncontrolled bunches of palm oil fuel ash (POFA) leads environmental pollution and hazardous to the human. Besides, POFA can be classified as the high pozzolan matter. This feature attracts attention tremendous researchers to identify the usage of POFA to overcome the abundant issues. This paper is review about the reuse a POFA in a different method. The researcher found the potential by replaced the cement with POFA in construction material. In addition, findings shows that POFA can be use to reduce carbon content, loss of ignition and increased mineral oxide composition. Yet, POFA has good high potential and can be used in construction industries

Keywords: *Concrete, Construction Material, Palm Oil Fuel Ash (POFA), Pozzolanic Matter.*

1. Introduction

Oil palm tree *(Elaeis guinensis*) is a tropical palm plant which is native to Africa [1]. Palm oil fuel ash (POFA) is a product from palm oil industry which it is has been burnt at 800–1000°C to produce steam. The combustion consists of use palm fiber, shell and empty fruit bunches of palm oil to generates turbine for supplying electrical energy to the whole mill for milling operation and domestic or estate use[2][3]. Malaysia can be classified as one of the largest region of produced palm oil with million tonnes generated annually. In Malaysia and Thailand, about three million tonnes and 100,000 tonnes of POFA produced in 2007 respectively [4][5].

Besides, Malaysia concern about uncontrolled dump POFA affected the human health and environment issues. Therefore, previously, POFA was studied the potential as fertilizer in agricultural industries. In 1990, researcher from Malaysia had started to study of POFA as supplementary cementing material [6]. In 1993, Sallihudin and Hussin [7] found the potential to minimize usage of POFA as cement replacement material but need to be monitor as well. Since then, tremendous researchers continued investigated the potential of POFA as cement replacement [6-11]. Therefore, this paper is discuss critically on findings of POFA potential in construction material.

2. Properties of POFA

2.1 Physical Properties

In term to ensure POFA are suitable as replacement cement, the physical properties be the main concern. Regarding Abdullah *et al.* [12], the burning condition and burning temperature give a major influenced to physical properties. Table 1 shows summary of properties of unground POFA and ground POFA from other researcher.

Table 1: Physical properties of POFA

Properties	Unground POFA	Ground POFA
Color	Light grey whitish	Dark grey
Specific gravity	1.78-1.97	2.22-2.78
Median Particle size, d_{50} (µm)	54.3-18.3	7.2-10.1
% Passing through 45µm sieve (% mass)	5.6 – 58.8	97-99
Specific surface area, Blaine (m^2/kg)	796	882-1244
Strength activity index (%)	-	78.6-115
Soundness, Le Chatelier expansion (mm)	0.5-2.6	1

The colour of ground POFA is more darker compared to unground POFA. This is happened due to unburnt carbon content left with the higher burning temperature [13]. For the specific gravity, the ground POFA is more heavier than unground POFA. Thus, the ground POFA tends to more suspended in air. Other than that, the size of particle also different for ground and unground POFA. Table 1 shown that the unground POFA have bigger particle size than ground POFA. Besides, other important physical component is fineness. The fineness can affect the rate of hydration and pozzolanic reaction [14]. Besides, to get a rapid development of strength, the high fineness is required. As shown in Table 1, the ground POFA is more fineness than unground POFA. The particle size of POFA can be reduced by the grinding process in ball mills [3],[15],[16]. The grinding process reduces not only the particle size but also the porosity of POFA [14]). After grinding, POFA is less porous with smaller particles [13]. Usually, the fineness measured for supplementary cementing material based on specific surface area of the particle it can be seen in Table 1. The Fig. 1 shows the distribution of particle for POFA.

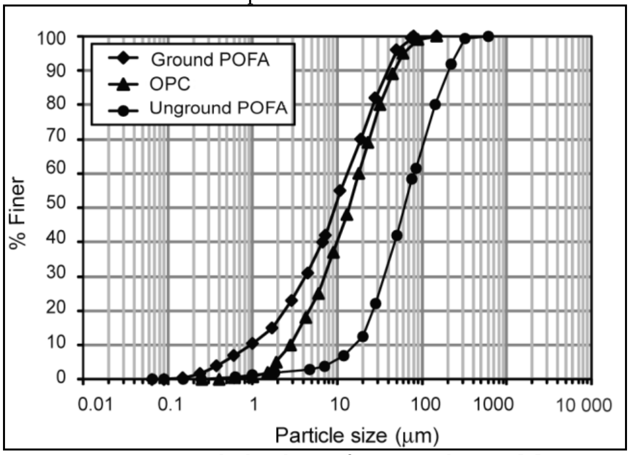

Fig. 1: Particle distribution for OPC and POFA [8]

The grinding process also affect the strength activity index. To determine the strength activity index, it can be measure by testing the compression strength using mould 50mm with or without supplementary cement material [17]. The minimum strength activity index is 75% for fly ash which same with POFA. All the strength activity index relies to the silica content, particle size distribution and surface area to increase the fineness of POFA through grinding process [10]. Lastly, soundness of POFA can also be determined by follow the procedure mentioned in ASTM C311-07 [17]. Soundness can affect the expansion of POFA blended cement paste.

3. Chemical Composition

Other than physical properties, chemical composition also play it role to contribute the selection of supplementary cementing material. Table 2 summarized of chemical composition done by Safiudin *et al.* [18].

Highest composition of POFA is Silica Oxide (SiO_2) which in range 44-66%. Then, other high component measured were Al_20_3 and Fe_2O_3. By comparing to ASTM C618-08 [19], Na_2O had over the maximum limit. Other components, namely, SO_3 was below the limit. According to Safiudin *et al.*[18], the composition SiO_2 $+Al_2O_3+Fe_2O_3$ of POFA achieved the requirement for pozzolanic and lower than minimum requirement in ASTM C618-08 (2008) [3],[8]. Therefore, POFA can be classified as natural pozzolan and requirement to be supplementary cementing materials must under the Class F [2]. From the table 2, percentage of mass for each component were varies due to the condition of burning POFA.

4. Physiochemical Characteristic

Table 3 is the summary of the physiochemical characteristic POFA. From Table 3, the size of POFA particle is more 50%.wt larger than 500µm. It was expected as combustion in boiler compared incinerator industrial where doing combustion inconsistent due to protect environment. For this size particle POFA, it has been suggested to use as cement replacement material because surface areas of small ash particles is higher compared to that of large ash particle [13]. For loss on ignition analysis, it shows that POFA contains high percentage of organic content. This is because have some of the residue palm oil not fully burnt during burning. With this high of organic content, POFA can be used as cement replacement material[20].

In addition, organic compound has good effect on cement hydration reactions and adversely affect the microstructural, mechanical and leaching properties of the cementitious materials [20]. A standard procedure used to determine a leaching condition in presence of organic is toxicity characteristic leaching procedure (TCLP) Method 1311 [21]. There are the limit for leachability for hazardous treatment in Malaysia which conducted by Kualiti Alam Sdn Bhd and limit leachability is 1 mg/L for cadmium, lead, copper and nickel [22].

Table 2. Chemical composition of POFA [18]

Chemical component	POFA (% mass)	Chemical compo-nent	ASTM C618-08 (2008) requirement		
			F*	C*	N**
SiO_2	44-66	-	-	-	SiO_2
Al_2O3	1.5-11.5	-	-	-	Al_2O3
Fe_2O3	1.5-5.5	-	-	-	Fe_2O3
$SiO_2+Al_2O_3+Fe_2O_3$	55-70	70 (min)	50 (min)	70 (min)	$SiO_2+Al_2O_3+Fe_2O_3$
CaO	4-8.5	-	-	-	CaO
MgO	2-6.5	-	-	-	MgO
K_2O	2-8.5	-	-	-	K_2O
Na_2O	0.1-3.5	1.5 (max)	1.5 (max)	1.5 (max)	Na_2O
SO_3	0.2-3.0	5 (max)	5 (max)	4 (max)	SO_3
SiO_2	44-66	-	-	-	SiO_2

*****Class F fly ash,
C*: Class C fly ash,
N**: Raw or calcined natural pozzolan

Table 3: Physiochemical characteristic [23]

Particles size distribution	
>500µm (wt. %)	**54.43**
400 – 500 µm (wt. %)	**12.78**
300 – 400 µm (wt. %)	**15.93**
212 – 300 µm (wt. %)	**14.00**
125 – 212 µm (wt. %)	**2.84**
<125 µm (wt. %)	**0.01**
Elemental analysis	
Carbon (wt.%)	**7.93**
Hydrogen (wt.%)	**1.47**
Nitrogen (wt.%)	**0.05**
Other (wt.%)	**90.55**
Loss of ignition analysis	
Organic content (wt.%)	**14.25**
TCLP analysis	
Copper (mg/L)	**0.09**
Lead (mg/L)	**0.12**
Nickel (mg/L)	**0.09**
Leachate pH	**10.80**

5. Effect of POFA in concrete

5.1 Workability

Workability of concrete decreased when POFA content increased and it shows in Table 4 [8],[24],[25]. Mixtures tend have low slump and degree compaction due to the high content of POFA. In addition, POFA required more water for lubricated a concrete compare OPC, which has similar workability with OPC[4]. Because of POFA has higher porosity, water absoption is needed to reduce free water content. Besides, the increased of water demand can be influence by angularity and irregularity of ground POFA with porous particles and also might be reduced loss of ignition (LOI) [4],[12].

Table 4 Effects of POFA on workability concrete [24], [15],[26]

Cement replacement by POFA (wt%)	Unground POFA		Ground POFA	
	Slump (mm)	Compact factor (%)	Slump (mm)	Compact Factor (%)
0	150	0.975	200	0.970
10	150	0.970	200	-
20	140	0.960	185	0.950
30	130	0.955	185	0.930
40	130	0.950	-	-
50	120	0.950	-	-

5.2 Compressive Strength

Based on previous studies, the compressive strength decreased when the higher content POFA added [26],[25]. In contrast, other researchers revealed that concrete made from POFA has higher compressive strength compared to OPC only [16]. When 10% unground POFA added to mixtures the strength is similar OPC only. When unground POFA content increase with range from 20 to 50%, the compressive are decreased [26]. Fig. 2 shows the effect unground POFA on compressive strength.

According to [27], due the low pozzolanic activity found in POFA at the early age, the low compressive strength of the mixtures was measured. However, at the end of the curing, the strength POFA is higher than OPC concrete. The study also found at 20% of POFA, the optimum strength was detected. Thus, addition of POFA at mixtures required longer duration to achieved high strength.

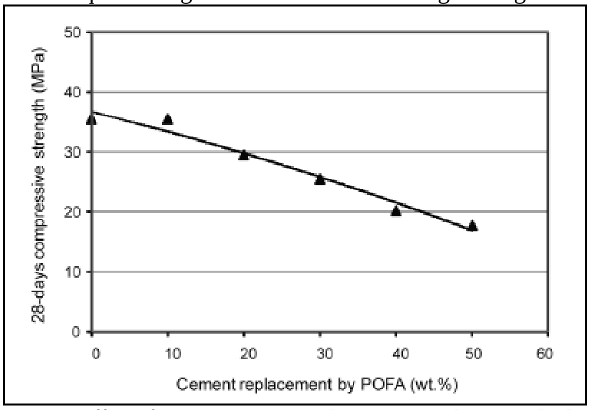

Fig. 2: Effect of compressive strength in POFA replacement [26]

Besides, Tangchirapat *et al*.[3] revealed that concrete contained 10–30% ground POFA tend to have a higher compressive strength than OPC concrete at 28 days. Fig. 3 will show effect strength POFA in different ages.

According to Isaia *et al*. [28] for ground POFA particles, the micro–voids are fill between the cement particles due to smaller particles. These micro-filling can increase the compressive strength concrete in early ages. Besides, from the cement hydration SiO_2 ground POFA reacted with Ca $(OH)_2$ due to presence of water and form or secondary calcium silicate hydrate (C–S–H). Main contribution for compressive strength of concrete is pozzolanic reaction when it can improvised the the interfacial bond between paste and aggregate in later ages [15]. All the micro-filling activity and pozzolanic activity is depends on w/b ratio of concrete.

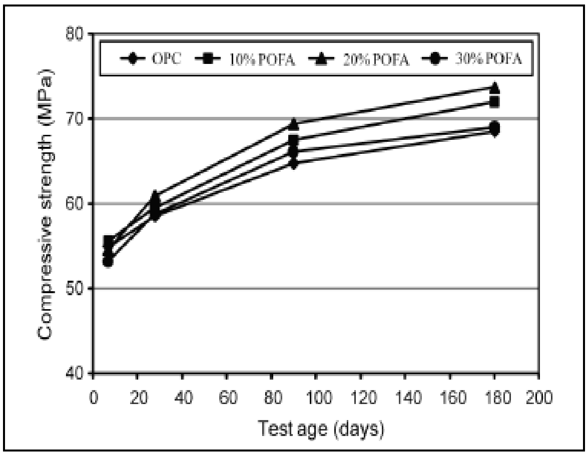

Fig. 3: Effect strength POFA in different ages [26].

5.3 Setting Time

POFA can be uses to delay the setting of concrete and it also can increase times with higher of POFA content [3],[25],[26]. The summary of studies as shown in Table 5. According to ASTM C150/C150M-09 [29], even though time setting of POFA concrete increased, it still under ASTM requirement. In on the other sides, there are some argument that shows POFA concrete with varies ash did not fulfilled the requirement of ASTM C150/C150-09 2009 [25],[26]. However, due to pozzolanic reaction which involved POFA and calcium hydroxide, the hydration of cement is slow when the POFA concrete have long setting time. Besides, POFA has high porosity and all the particles was absorbed by water and effect on hydration effect. Because of that, it has increased the setting time of concrete[3].

Table 5 Setting time effects on POFA contents [30],[26]

Cement replace-ment by POFA (wt.%)	Initial setting time*		Final setting time**	
	Unground POFA	Ground POFA	Unground POFA	Ground POFA
0	2 hr 5 min	4 hr 10 min	3 hr 15 min	6 hr 30 min
10	2 hr 10 min	4 hr 25 min	3 hr 45 min	6 hr 35 min
20	2 hr 10 min	4 hr 35 min	4 hr 0 min	7 hr 00 min
30	2 hr 20 min	4 hr 50 min	4 hr 10 min	7 hr 25 min
40	2 hr 30 min	5 hr 10 min	4 hr 30min	7 hr 40 min
50	2 hr 40 min	-	4 hr 40 min	-

*ASTM C150/C150M-09 (2009) requirement: not < 45 min; ** ASTM C150/C150M-09 (2009): not > 6 hr 15 min

6. Analysis Fourier-Transform Infrared Spectroscopy (FTIR)

For FTIR analysis, the result as shown in Fig. 4 for FTIR transmission spectrum of POFA. The peak observed at 1050 cm^{-1} which it assigned to bond for a bonding from polycondensation with alternating Si–O and Al–O bonds [31]. For the lowest peak, it is assigned Al–O or Si–O–Al is about 800 cm^{-1} [32]. The analysis of FTIR is to detect the presence of silica where the main component of building in cement and concrete potential. According to Tay and Show [25] the POFA has the potential to be a cement replacement material.

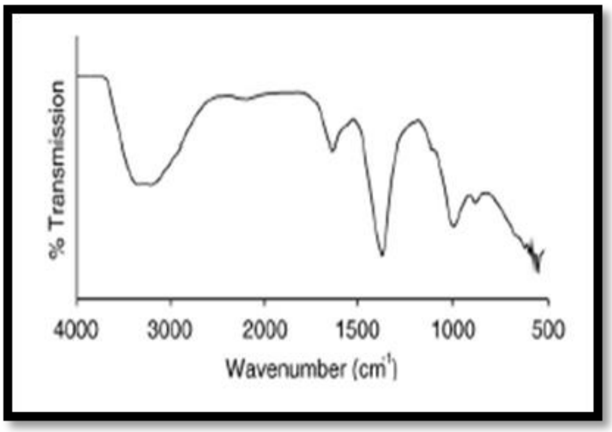

Fig. 4: FTIR analysis [31]

7. Conclusion

The usage of POFA can be varied. These has been show and confirmed based on the research conducted. From the findings, it shows that chemical and physical properties POFA good for production concrete. The usage of POFA into a concrete as replacement would not affect durability of concrete. Besides, the POFA replacement can be up until 30% of cement content. If use up until 40% of POFA, it will affect the strength of concrete. Not only that, The fineness of POFA will improves the micro filling ability and pozzolanic activity in term to improve the hardened properties and durability concrete. Lastly, this study will solve the problem of abundant palm oil ash by using POFA as supplementary cementing material in concrete and also will reduce environmental wastes. Yet, another research should be conducted to extend the use of POFA in self consolidating normal strength, high strength and high-performance concrete.

Acknowledgement

Special thanks to University Tun Hussein Onn Malaysia for providing facilities and hospitality during study. We thank to the editor, associate editor and reviewers for their contrastive comments that improved the quality of this article. This research was sponsored, in part, by Postgraduate Research Grant (GPPS) U789 and Incentive Grant Scheme for Publication (IGSP) U680.

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