Influence of Palm Oil Fuel Ash on Properties of High-Strength Green Concrete

Abdullah. M. Zeyad[(1)], Megat Azmi Megat Johari[(2)], Bassam A. Tayeh[(3)], Ibrahim M. Alshaikh[(2)(4)]

(1) Civil Engineering Department, Jazan University, Saudi Arabia
(2) School of Civil Engineering, Universiti Sains Malaysia
(3) Civil Engineering Department, Islamic University of Gaza, Gaza, Palestine
(4) Civil Engineering Department, University of Science and technology, Yemen

Received 25 October 2017 - Accepted 02 August 2018

ABSTRACT
Palm oil ash wastes are normally used as fuel to heat up boiler for electricity generation in palm oil mills. This process leads to the production of unwanted ash residue which is known as palm oil fuel ash (POFA). The sufficiently amorphous POFA contains a high amount of silica, which makes it possible to be used as a pozzolanic material in concrete. POFA was treated to lower the unburned carbon and to reduce the particle size and then used in the production of high strength concrete by partially substituting ordinary Portland cement (OPC) at replacement levels of 0%, 10%, 20%, 30%, 40%, 50 and 60% on the mass-for-mass basis. The results show that the high strength green concrete containing POFA has superior workability, strength and transport properties when compared with the control OPC high strength concrete even at high POFA content of 60%. Hence, the treated POFA has promising potential to be utilized in the production of high strength green concrete with superior strength and transport properties. This could directly contribute to the sustainability of the concrete industry, via the utilization of agro-industry by-product in high strength green concrete with lower cement consumption and potentially superior durability performance.

Key Words: High- strength green concrete, Palm ash, Strength, Transport properties, Workability.

INTRODUCTION
Palm oil industry is one of the most important agro-industries in Malaysia, nonetheless the industries produce a large amount of by-product ash residue (POFA) (Abdul Awal and Hussin, 1997; MPOB, 2009). POFA must be disposed of as solid waste because of the growing concern of pollution and worries over environmental degradations, such as global warming and at-mospheric pollutions (MPOB, 2017). The use of agricultural wastes as pozzolanic materials has received more attention since their exploitation tends to improve the characteristics of the blended cement for produce high-quality concrete and addition to decrease the potenetial environmental problems. This could be realized via the utilization of harmful waste like POFA safely and permanently in high strength concrete (HSC) which at the same time could improve the properties and potential durability performance of the HSC (Sata *et al.,* 2004; Chindaprasirt *et al.,* 2008; Tangchirapat *et al.,* 2009). Studies have shown that POFA can be used as pozzolan in concrete by big rate of up to 30% from weight of cement and also fine POFA is classified as pozzolanic material and can be used as a replacement of Portland cement at a rate ranging between 20-30% (Sata *et al.,* 2007; Chindaprasirt *et al.,* 2008; Tangchirapat *et al.,* 2009; Zeyad 2017.). Nonetheless, during the treatment process, care should be taken neither to induce crystallization nor particle agglomeration, which could affect the reactivity of the treated ashes (Chandara et al., 2010; Zeyad et al., 2017). Early study however found that POFA has weak pozzolanic properties and should not be used as alternative to the cement greater than 10% by mass of binder (Tay, 1990). The aim of this study is to utilize treated POFA as a supplementary cementitious material by replacing high volume of cement to produce high strength green concrete (HSGC). POFA is used as partial cement substitute on mass-

for-mass basis at substitution levels of 0, 10, 20, 30, 40 and 60% and the influence of the POFA inclusion will be quantified. Figure 1 shows waste dumping site, and figure 2 shows Process stages of treatment palm oil fuel ash.

Fig 1: Dumping site for POFA

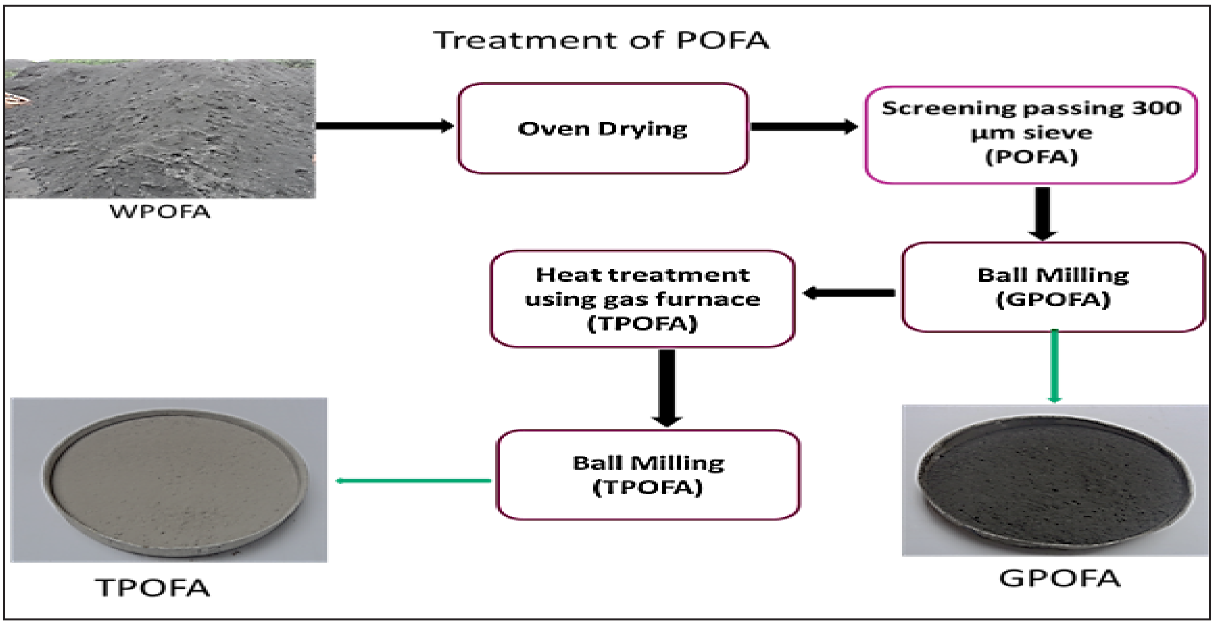

Fig 2: Process stages of treatment palm oil fuel ash

MATERIALS AND METHODS

Materials

Type I Portland cement that complies with ASTM C150 (2001) was used as the main binder. Waste produced from palm oil fuel was used as a supplementary binder in concrete manufacture. The waste of palm oil fuel ash (WPOFA) was first dried in an oven at 105 ± 5 °C for 24 ± 1 h to achieve 100% drying to facilitate the milling process. Then, WPOFA was sieved using a 0.30 mm mesh to remove the coarse particles that were incompletely combusted in the boiler. Thereafter, WPOFA was subjected to heating and grinding processes to obtain treated POFA (TPOFA) (Zeyad *et al*., 2017). Table 1 presents the physical properties of TPOFA together with those of Portland cement. Local river sand was used as a fine aggregate with fineness modulus, specific gravity, and water absorption rate of 3.1, 2.7, and 0.62%, respectively. The sand was washed to remove any organic particles and then dried in an oven at 105 °C for 24 ± 1 h. The natural source of coarse aggregate is granite rocks, which were used as coarse aggregates with maximum size, specific gravity, water absorption, and bulk density of 12.5 mm, 2.66, 0.48%, and 1520 kg/m³, respectively. A type F polymer-based superplasticizer was used at a constant dosage of 2.2% by mass of binder to obtain high workability at low water content to achieve high strength.

Table 1: Physical characteristics of cement and TPOFA

Materials	Specific gravity	Average particle size (μm)	surface area (m²/g)
Cement Type I	3.10	6.79	0.78
TPOFA	2.56	2.06	1.77

Concrete Mix Proportions
The mix of concrete (OPC) was designed based on experimental mixtures to achieve high-strength concrete. Then, the treated POFA was used as a partial replacement of 10%, 20%, 30%, 40%, 50%, and 60% of cement mass. Table 2 presents the mix proportions of the OPC-HSC and TPOFA-HSC that were derived in accordance with ACI 211 guidelines (ACI 211, 1993).

Table 2: Mix proportions of high-strength concretes (kg/m³)

Materials	OPC	TPOFA 10%	TPOFA 20%	TPOFA 30%	TPOFA %40	TPOFA 50%	TPOFA 60%
Cement	550	495	440	385	330	275	220
Coarse aggregate	1033.6	1033.6	1033.6	1033.6	1033.6	1033.6	1033.6
Fine aggregate	741 .2	730 .3	719.4	708.5	697.6	686.7	675.8
Water	148.9	148.9	148.9	148.9	148.9	148.9	148.9
Superplasticizer	12.1	12.1	12.1	12.1	12.1	12.1	12.1
TPOFA	0	55	110	165	220	275	330

TESTING
Workability
Workability was assessed through a slump test in accordance with BS EN 12350 (BSI, 2000).

Compressive Strength
Concrete cubes with dimensions of 10.0 x 10.0 x 10.0 cm were utilized to determine the compression strength by using a 3000 KN machine in accordance with BS EN (BSI, 2002). The test was executed at ages of 1, 7, and 28 days.

Porosity, Water Absorption, and Surface Absorption
Tests were conducted to study how including TPOFA in samples of the high-strength concrete affects porosity, water absorption, and initial surface absorption. Tests for water absorption and porosity were conducted by using a vacuum saturation device (RILEM CP113, 1984) on samples with 5.5 cm diam5eter and 4.0 cm thickness of concrete core. The initial surface absorption test (ISAT) was performed on concrete cubes with 10 cm in accordance with the recommendations provided in BS 1881: Part 208 (BSI, 1996). Water absorption (WA) and porosity (P) were calculated using Equations 1 and 2, respectively, where W2 = sample mass fully saturated and surface dried in air, W3 = sample mass fully saturated in water, and W4 = sample mass after oven drying in air.

$$WA = (W2 - W4) / W4\times100 \quad \text{Eq.(1)}$$

$$P = (W2 - W4) / (W2 - W3) \times100 \quad \text{Eq.(2)}$$

Rapid Chloride Permeability
In this investigation, rapid chloride permeability test was conducted in accordance with

ASTM 1202 (2004). Specimens with dimensions of 10.0 cm diameter and 5.0 cm thickness were cut from 10.0 cm x 20.0 cm concrete cylinders. The resistance of the sample to chloride ion penetration was obtained by reading the total charge passed (TCP) through concrete samples.

WA = (W2 - W4) / W4×100…..………...…….Eq.(1)

P = (W2 - W4) / (W2 - W3) ×100……………Eq.(2)

RESULTS AND DISCUSSION

Workability

Figure 3 shows the results for workability through the slump test.

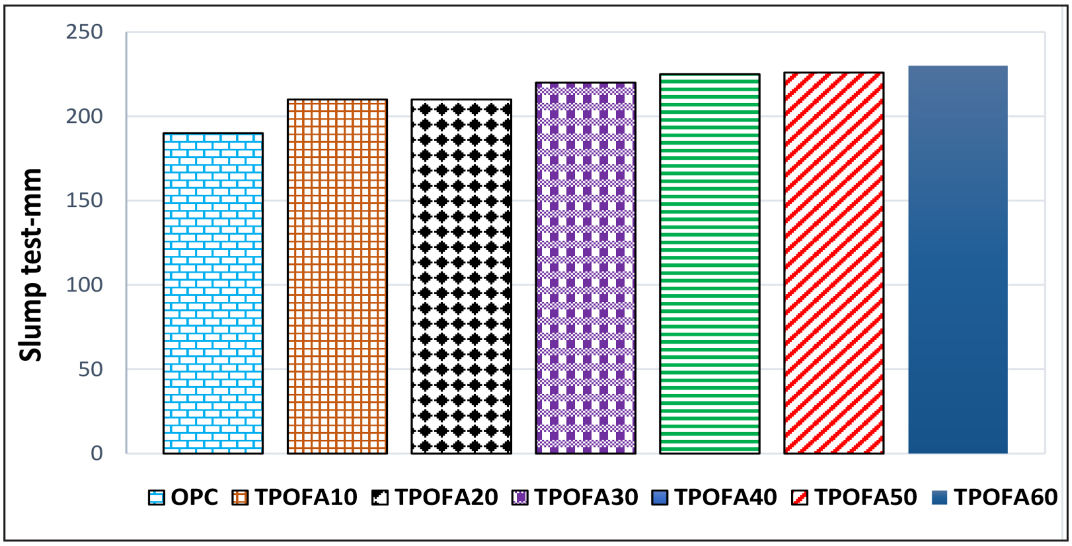

Fig 3: Results of slump test

Adding POFA improved the workability of HSC. Moreover, high POFA content resulted in high workability. As the water/binder ratio and dosage of superplasticizer were kept constant for all mixes, the inclusion of TPOFA seems to reduce the water demand, which leads to high workability. This condition could be explained by a low dosage of superplasticizer to achieve constant of slump test. In fact, the addition of TPOFA reduced the cement content with maintained superplasticizer percentage and the water–cement ratio, which contributed to the increase in slump value. Various trends were previously reported on HSC containing GPOFA as an increase in the dosage of superplasticizer was noted at high GPOFA content to keep a constant slump (Sata *et al.,* 2004; Tangchirapat *et al.,* 2009). Removal of carbon from GPOFA could have contributed to the increased workability because the carbon disrupts the interaction between cement particles and superplasticizer, thereby hindering the adsorption and electrostatic repulsion mechanisms and impairing the workability.

Compressive Strength

Figure 4 illustrates that the addition of TPOFA decreased the strength of the HSC at the early age, with a high reduction when the POFA content is high. This phenomenon may be attributed to replacing part of the cement with TPOFA. At 1-day age, the HSC mixes were reduced in strength by 24%, 29%, 39%, 43%, and 59% for POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively, in comparison with OPC as shown in Figure 5. Nonetheless, the prolonged water curing period improved the compressive strength of the HSC containing TPOFA. At 7-day age, the strength of the concrete increased and decreased as follows: 86.9, 87.1, 87.4, 85.2, 84.9, 80.2, and 79.4 MPa for OPC, POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively. However, at 28-day age, a significant increase in compressive strength could be observed for concrete containing TPOFA, as shown in Figures 4 and 6. POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60 increased in strength at 28-day age by 3%, 8%, 15%, 14%, and 7%, respectively, in comparison with OPC, as shown in Figure 5. This noted increase was a result of the pozzolanic reaction between TPOFA and calcium hydroxide, thereby producing a secondary calcium silicate hydrate (C-S-H) that was densified concrete microstructure and increased concrete strength.

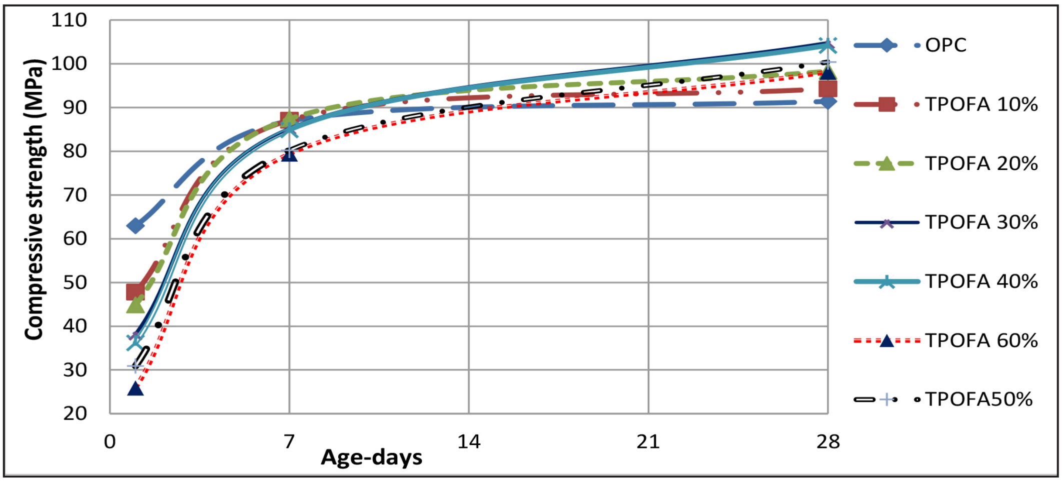

Fig 4: Influence of TPOFA on compressive strength of HSC

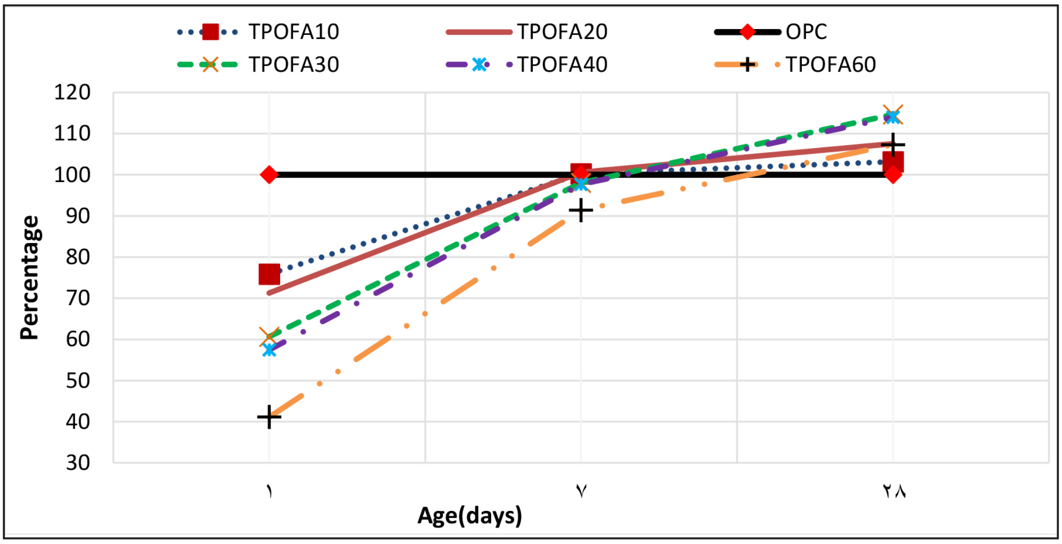

Fig. 5: Influence of TPOFA on compressive strength of HSC

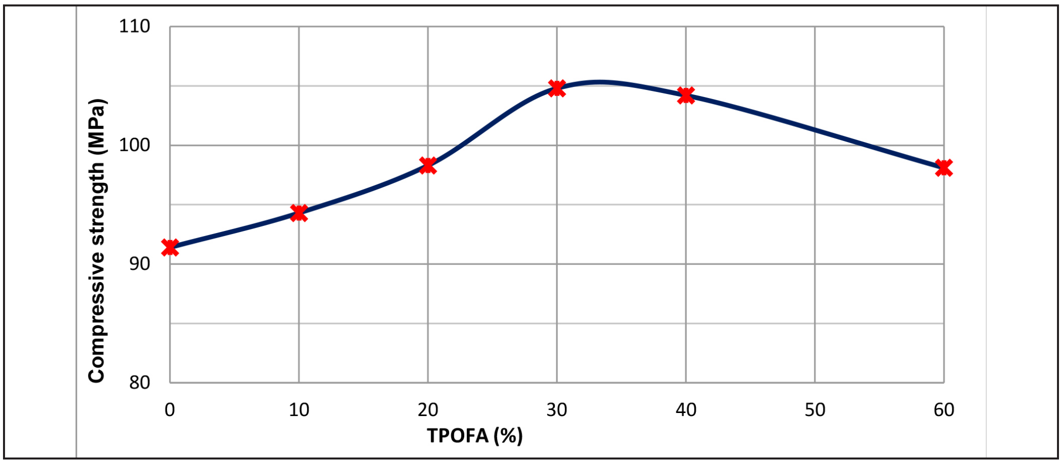

Fig. 6: Influence of TPOFA on compressive strength of HSC at 28 days

Porosity, Water Absorption, Initial Surface Absorption, and Rapid Chloride Permeability

The test results for porosity, as shown in Figure 7, demonstrate that using TPOFA reduces the porosity of the HSC at 28 days. The recorded porosity is 7.82%, 7.1%, 6.94%, 6.13%, 6.02%, 5.94%, and 5.75% for OPC, POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively. Thus, the reduction in porosity is significant at high TPOFA content. Similar to porosity, HSC possesses lower water absorption than OPC at all testing ages, as shown in Figure 8. The recorded values of water absorption at 28 days are 3.24%, 3.11%, 2.88%, 2.55%, 2.53%, 2.48%, and 2.44% for OPC, POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively. In addition, a distinct trend is observed in which water absorption reduces with increasing TPOFA content. Figure 9 presents the results of the ISAT performed at 28 days for a time interval of 10 min and 1 h. Results show that the inclusion of TPOFA reduces the initial surface absorption of the HSC. Results for ISAT at 10 min are 0.12, 0.1, 0.075, 0.066, 0.06, 0.058, and 0.055 ml/m^2/s for OPC, POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively. By contrast, the results at 1 h are 0.05, 0.043, 0.032, 0.03, 0.03, 0.029, and 0.021 ml/m^2/s for OPC, POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively. The noted decrease in initial surface absorption, porosity, and water absorption could be attributed to the increased microstructure density of the POFA-high-strength green concrete (HSGC) resulting from the pozzolanic reaction of TPOFA, particularly at long water curing period and high POFA content.

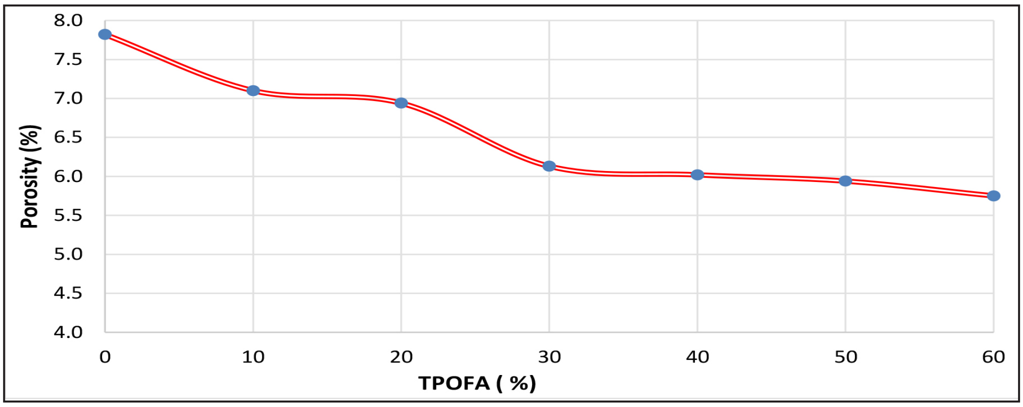

Fig. 7: Influence of TPOFA on porosity of HSC at 28 days

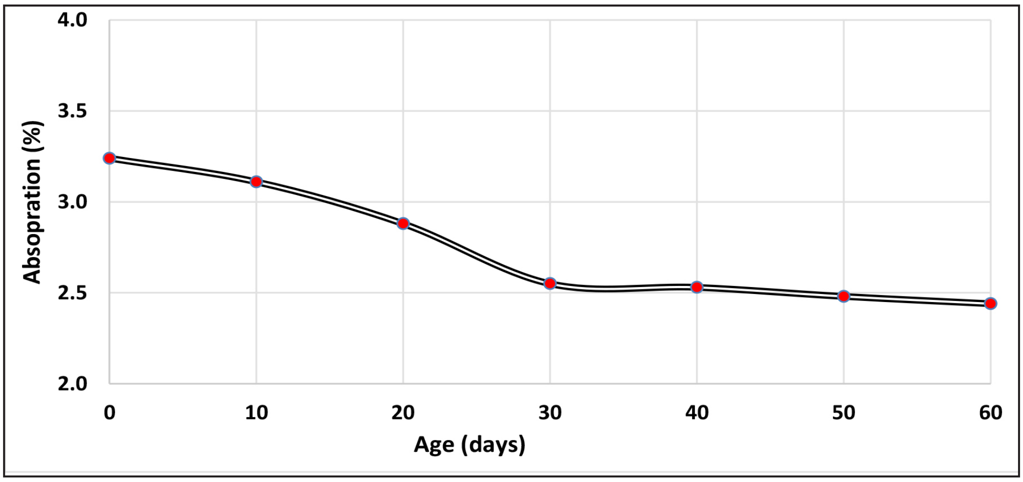

Fig. 8: Influence of TPOFA on water absorption of HSC at 28 days

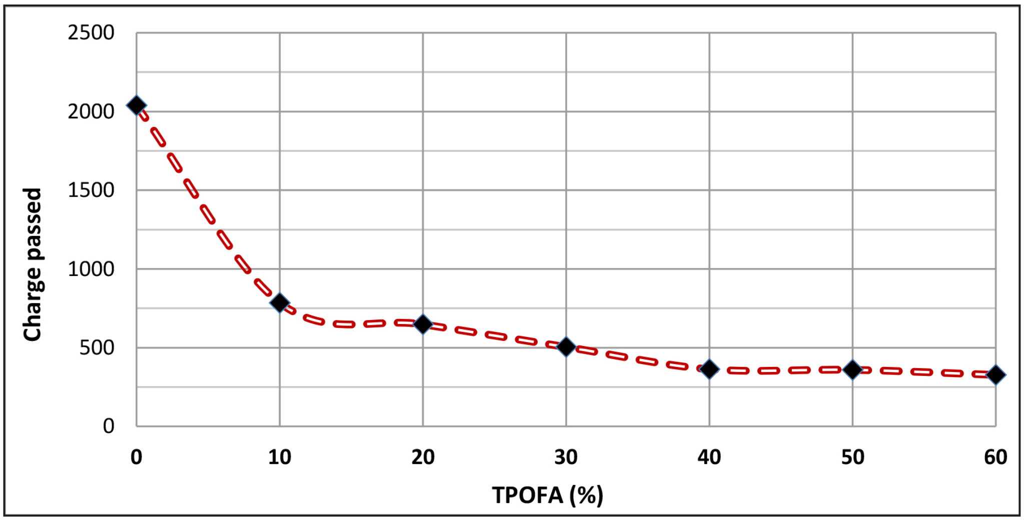

Fig. 9: Influence of TPOFA on ISAT of HSC at 28 days

The rapid chloride penetration test was conducted to estimate the chloride resistance performance of HSC and TCP, as shown in Figure 10. The TCP values of POFA-HSGC significantly decrease in comparison with those of OPC-HSC. At 28 days, a significant and consistent trend is observed in which the TCP values decrease with increasing POFA content. The TCP values are 2038, 785, 648, 504, 363, 359, and 327 coulombs for OPC, POFA10, POFA20, POFA30, POFA40, POFA50, and POFA60, respectively. The significant reduction in TCP values, particularly at high POFA content, could be due to the reactive nature and fineness of TPOFA used in this study, thereby decreasing the rapid chloride permeability of HSC at high POFA content of 60%.

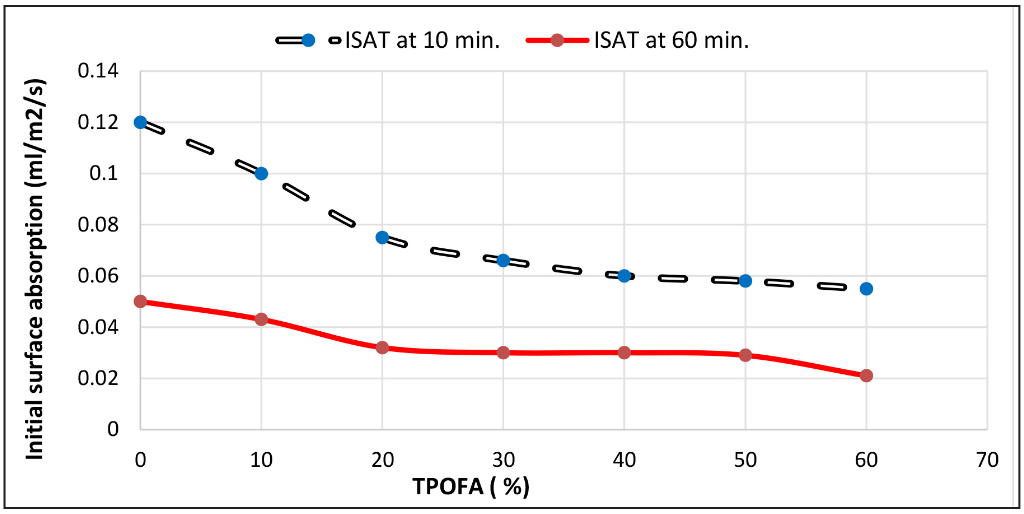

Fig. 10: Influence of TPOFA on rapid chloride permeability of HSC at 28 days

CONCLUSIONS

Based on the findings on the characteristics of HSGC containing a large quantity of TPOFA, the following conclusions are presented:

1. The inclusion of TPOFA in HSGC with constant water/binder ratio reduced the water demand of HSGC with high workk ability at a high POFA content.
2. TPOFA-HSGC appeared to have low compressive strength at early ages of 1 and 7 days, particularly at a high TPOFA content, but after 28 days of water curing period, the compressive strength showed an opposite trend. All replacement rates of POFA (10%, 20%, 30%, 40%, 50%,

and 60%) recorded higher compressive strength than those of OPC-HSC. The replacement of TPOFA by 30% of cement mass (POFA30) exhibited the highest compressive strength at 104.8 MPa at 28 days.

3. The inclusion of TOPFA in HSGC reduced the porosity, water absorption, initial surface absorption, and permeability of rapid chloride at 28 days. In addition, compared with the results for OPC-HSC, the replacement of TPOFA by 60% of cement mass recorded a higher reduction in the porosity, water absorption, initial surface absorption, and permeability of rapid chloride at 28 days.
4. The treated POFA was proven to be a highly efficient pozzolan, which enhances the engineering and transport characteristics of HSGC. Thus, HSGC could be produced using a large quantity of treated POFA with potentially excellent characteristics, high performance, and durability.

REFERENCES

Abdul Awal, A. S. M., and Hussin, M. W. 1997. The effectiveness of palm oil fuel ash in preventing expansion due to alkali-silica reaction. Cement and Concrete Composite. 19: 367-372.

ACI Committee 211. 1993. Guide for selecting proportions for high-strength concrete with portland cement and fly ash. ACI 226.4R. ACI Materials Journal. 90: 272-283.

ASTM C 150. 2014. Standard specification for portland cement. Annual Book of ASTM Standards.4(1):149–155.

ASTM C1202. 2014. Standard test method for electrical indication of concrete's ability to resist chloride ion penetration. Annual book of ASTM standards. 4(2): 649-654.

Zeyad, A. M., Megat Azmi, M. J., Tayeh, B. A., and Yusuf, M.O. 2016. Efficiency of treated and untreated palm oil fuel ash as a supplementary binder on engineering and fluid transport properties of high-strength concrete. Construction and Building Materials 125: 1066-1079.

Zeyad, A. M., Megat Azmi, M. J., Tayeh, B. A., and Yusuf, M.O. 2017. Pozzolanic reactivity of ultrafine palm oil fuel ash waste on strength and durability performances of high strength concrete. Journal of Cleaner Production 144: 511-522.

Zeyad, A. M. 2017. Effect of curing methods in hot weather on the properties of high-strength concretes. Journal of King Saud University - Engineering Sciences, <https://doi.org/10.1016/j.jksues>. Access on 4.4.2017.

British Standard Institution (BSI). 1996. BS 1881: 208. Recommendations for the determination of the initial surface absorption of concrete. BSI. London.

British Standard Institution (BSI). 2000. BS EN 12350-2. Testing fresh concrete. Slump test. BSI. London.

British Standard Institution (BSI). 2002. BS EN 12390-3. Testing hardened concrete. Compressive strength of test specimens. BSI. London.

Chandara, C., Sakai E., Mohd Azizli, K. A., Ahmad, Z. A, and Saiyid Hashim, S.F. 2010. The effect of unburned carbon in palm oil fuel ash on fluidity of cement pastes containing superplasticizer. Construction and Building Materials. 24: 1590–1593.

Chindaprasirt, P., Rukzon S, and Sirivivatnanon, V. 2008. Resistance to chloride penetration of blended Port-land cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Construction and Building Materials. 22:932–938.

Malaysian Palm Oil Board (MPOB). 2017. Economic and statistic, <http://cutt.us/MAhlH>. Access on 4.4.2017.

RILEM CP113. 1984. Absorption of water by immersion under vacuum. Materials Structure Research Testing. 101:393-394.

Sata, V., Jaturapitakkul, C., and Kiattikomol, K. 2004. Utilization of palm oil fuel ash in high-strength concrete. Journal of Materials Civil Engineering. 16: 623-628.

Sata, V., Jaturapitakkul, C, and Kiattikomol, K. 2007. Influence of pozzolan from various by-product materials on mechanical properties of high-strength concrete. Construction and Building Materials. 21:1589-1598.

Tangchirapat, W., Jaturapitakkul, C., and Chindaprasirt, P. 2009. Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete. Construction and Building Materials. 23:2641-2646.

Tay, J. H. 1990. Ash from oil-palm waste as concrete material. Journal of Materials Civil Engineering. 2(2): 94-105.

تأثير رماد وقود زيت النخيل على خصائص الخرسانة عالية القوة الخضراء

عبد الله محسن زياد[1]، ميقات عزمي ميقات جوهري[2]، بسام عبد الرحمن تايه[3]، إبراهيم محمد الشيخ[4]

(1) قسم الهندسة المدنية، جامعة جازان، المملكة العربية السعودية

(2) كلية الهندسة المدنية، جامعة العلوم الماليزية، ماليزيا

(3) قسم الهندسة المدنية، الجامعة الإسلامية في غزة، فلسطين

(4) قسم الهندسة المدنية، جامعة العلوم والتكنولوجيا، اليمن

استلام **25** أكتوبر **2017**م - قبول **02** أغسطس **2018**م

الملخص

يتم استخدام نفايات صناعة زيت النخيل عادة كوقود لتسخين المرجل لتوليد الكهرباء في مصانع زيت النخيل، هذه العملية تؤدي إلى إنتاج بقايا الرماد غير المرغوب فيه، الذي يعرف باسم رماد وقود زيت النخيل. يحتوي رماد وقود زيت النخيل على كمية عالية من السليكا غير المتبلورة؛ مما يجعل من الممكن استخدامها كمادة بوزلانية فعالة في إنتاج الخرسانة، تتم معالجة رماد وقود زيت النخيل لخفض الكربون غير المحترق وخفض حجم الجسيمات ثم استخدامها في إنتاج الخرسانة عالية القوة عن طريق استبدال جزئي للأسمنت البورتلاندي العادي عند مستويات استبدال 0 %، 10 %، 20 %، 30 %، 40 %، 50 % و60 % من كتلة الأسمنت.

أظهرت النتائج إمكانية إنتاج خرسانة خضراء عالية القوة وأن الخرسانة التي تحتوي على رماد وقود زيت النخيل لديه قابلية تشغيل متفوقة ومقاومة للانضغاط الأعلى وذات خواص انتقالية أفضل بالمقارنة مع الخرسانة عالية القوة التي لا تحتوي على رماد وقود زيت النخيل، حتى مع استبدال محتوى عالٍ من الأسمنت يصل إلى 60 % من كتلة الأسمنت، وبالتالي فإن رماد وقود زيت النخيل المعالج لديه إمكانات واعدة لاستخدامه في إنتاج الخرسانة عالية القوة الخضراء مع قوة متفوقة وخصائص انتقالية جيدة، ويمكن أن يسهم ذلك بشكل مباشر في استدامة الصناعة الخرسانية؛ من خلال استخدام المنتج الثانوي للصناعات الزراعية في الخرسانة الخضراء عالية القوة مع انخفاض استهلاك الأسمنت وأداء متانة متفوق.

الكلمات المفتاحية: الخرسانة عالية القوة الخضراء، خصائص الانتقال، رماد وقود زيت النخيل، قابلية التشغيل، مقاومة الانضغاط.