



An Application of Blended Palm Oil Waste in Brick Production

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ABSTRACT

Cement brick is an essential construction component, which uses cement as the primary binder. The cement industry was identified as the major contributor to carbon dioxide emission, which is a greenhouse gas. The application of agro-industrial waste as partial cement replacement can reduce the negative impacts on the environment. In this study, the palm oil wastes, namely Palm Oil Clinker Powder (POCP) and Palm Oil Boiler Ash (POBA), were used as partial cement replacement. A total of 60 specimens were prepared with 0%, 10%, 20%, and 30% cement replacement by POCP and POBA. The physical and mechanical properties of bricks, such as density, water absorption, voids, and compressive strength, were investigated. The results show that the brick with 20% CP and BA could be used as a severe weathering brick.

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1. INTRODUCTION

Cement production is one of the highest carbon dioxide (CO₂) emission contributors among various industrial activities. It contributed 5% to 8% of the total global CO₂ emission (Kajaste and Hurme, 2016). According to Flatt (2012), the chemical decomposition of limestone during cement production releases a vast sum of CO₂, a greenhouse gas that traps heat in the Earth's atmosphere. For their environmental impacts, greenhouse gases

have drawn attention worldwide, seeking technological or technical solutions for the global warming problem. The Malaysian government has promoted a low-carbon economy by providing integrated sustainable development policies for all socio-economic sectors (Ministry of Natural Resources and Environment Malaysia, 2014). There is a need to reduce cement consumption in the construction industry to support these policies.

Cement comprises approximately 91% of clinker that is converted from

limestone. The large portion of clinker in cement could be replaced with supplementary pozzolanic material to produce blended cement, and this indirectly helps to reduce CO₂ emission by reducing the amount of cement used.



Figure 1. Palm oil boiler ash and palm oil clinker powder production.

Utilizing the waste from the agro-industrial processes in concrete and cement brick helps to consume the waste, and this can reduce the negative impacts on the environment (Ling et al. 2021). Palm oil boiler ash (POBA) and palm oil clinker (POC) are those from the palm oil industry (**Figure 1**). According to Karim et al. (2017), POBA can be used as a supplementary binder in the production of concrete and brick. Both POBA and POC powder (POCP) contain a high percentage of silica, which is vital for forming hydrated products. Some significant studies conducted by Ahmmad et al. (2016), Ahmmad et al. (2017), Kanadasan and Razak (2015), Kanadasan et al. (2018), Nayaka et al. (2018a), Nayaka et al. (2018b), Karim et

al. (2016), and Abutaha et al. (2016) had confirmed the feasibility of using POC as the supplementary binder, filler, and aggregate in the production of concrete and cement mortar. Kanadasan and Razak (2015) found that 100% cement replacement using POCP had elevated the slump flow of self-compacting mortar. Cement-lime replacement up to 40% with POCP attained minimum compressive strength of mortar (12.4 MPa) based on ASTM C270 – 14 (Nayaka et al., 2018a; Nayaka et al., 2018b). Karim et al. (2016) investigated the effect of thermal activated POCP in cement mortar, noticed a significant increase in the compressive strength of mortar. The significant increase was due to the decomposition of the organic compound that reduced the porosity of raw POCP. Based on these studies, the application of POCP seemed to have positive effects on mortar flow and strength.

Contrary to POC, feasibility study on the application of POBA as a construction material is very limited. Over the years, POBA was utilized as a bio-sorbent (Lau et al., 2019), a catalyst to transesterification of palm olein (Boey et al., 2011), silica gel (Kow et al., 2015), nanocomposite filler in thermoplastic (Bukit et al., 2018) and geopolymer (Yahya et al., 2015). POBA is typically found in powder form, and could replace cement or as a filler in concrete or cement mortar. Roslan et al. (2020) reported that 5% and 10% cement replacement by POBA could attain compressive strength beyond 30 MPa on day 28.

There has never been a study that used a combination of POBA and POCP as partial cement replacement from the literature review. Therefore, the physical and mechanical properties of bricks containing composite palm oil ashes (POBA and POCP) as cement replacement materials were studied and presented in this paper.

Table 1. Replacement level for POBA and POCP and Test Details.

Brick	CM	10BA+10CP	20BA+20CP	30BA+30CP
OPC	100%	80%	60%	40%
POBA	-	10%	20%	30%
POCP	-	10%	20%	30%
Test*	No. of Samples			
Density	3	3	3	3
Void content	3	3	3	3
Water Absorption	3	3	3	3
Compression	3	3	3	3
Weight Loss	3	3	3	3

*In accordance with ASTM C62-17

2. METHODOLOGY

The palm oil boiler ash (POBA) and palm oil clinker (POC) used in this study were collected from the palm oil mill in Mukah, Sarawak. The sand used was the river sand locally available in Sibul, Sarawak. The samples were prepared in powder form and stored in airtight containers. The materials properties such as density, specific gravity, chemical compositions, gradation, and morphology were obtained.

Four series of mixes were prepared. Control mix (CM) was made of ordinary Portland cement (OPC), sand, and water with a 1:3 (C:S) mixing ratio. The water/binder ratio and superplasticizer dosages were 0.6 and 1%, respectively. The modified mortar was a mixture of OPC, POBA, POCP, sand, and water. The replacement percentages of POBA and POCP are presented in **Table 1**. Nayaka et al. (2018a) and Nayaka et al. (2018b) recommended limiting the replacement of POCP at 40%. Thus, the exact replacement percentage was also applied for POBA.

The bricks were fabricated in the size of 215 mm × 90 mm × 70 mm. Bricks were removed from steel molds after 24 hours of casting and cured in water for 7 and 28 days. A total of 60 specimens were prepared (**Table 1**). Each mix comprised three specimens, and the average values were

taken. The density, water absorption, voids, and compressive strength of the bricks were measured at 7 and 28 days. Flow test for fresh mortar was conducted according to ASTM C1437.

3. RESULTS AND DISCUSSIONS

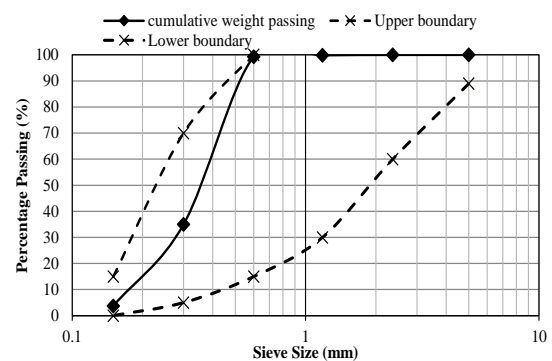
3.1. Material Properties

The density and specific gravity of materials are tabulated in **Table 2**. The density and specific gravity of POBA and POCP are 52.7% and 28.6% lower than OPC, respectively.

Table 2. Density and specific gravity of POBA, POCP, OPC and sand.

Material	Density (g/cm ³)	Specific Gravity
Palm Oil Boiler Ash	1.49	1.49
Palm Oil Clinker Powder	2.25	2.25
Ordinary Portland Cement	3.15*	3.16
Sand	2.54	2.54

*Karim et al. (2017)

**Figure 2. Gradation of sand.**

The average water absorption of sand was 0.4%, and the sieve analysis was presented in **Figure 2**. According to BS EN 12620 (British European Standard, 2013), the sand gradation fell under medium gradation with a fineness modulus of 2.61.

Table 3. Particle size of POBA, POCP and OPC.

Average Size (μm) ¹	POBA	POCP	OPC ²
D(u, 0.1)	6.36	2.76	-
D(u, 0.5)	24.5	11.3	27.98
D(u, 0.9)	105	788	-
Specific surface area (m^2/kg)	364.3	807.4	331.0

¹D = diameter, u = volume, 0.1, 0.5, 0.9 = percentage (10%, 50% and 90% respectively) of the particles are smaller than this diameter.

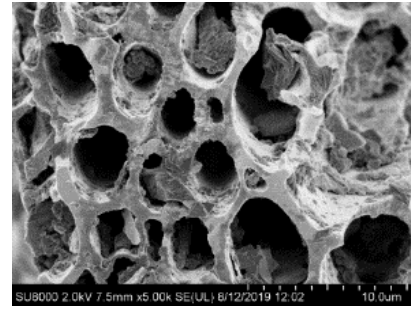
²Kanadasan and Razak, 2015

Table 4. Chemical compositions of OPC, POBA, and POCP (in %)

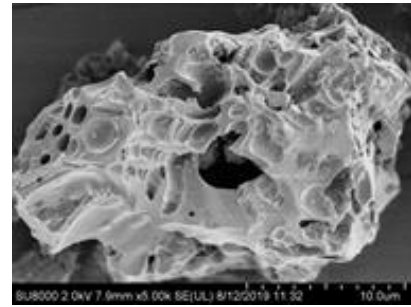
Composition	OPC	POBA	POCP
SiO ₂	20.29	30.5	56.6
Al ₂ O ₃	5.37	0.66	2.01
Fe ₂ O ₃	2.94	46	2.66
K ₂ O	0.17	10.2	9.01
CaO	64	4.93	25.7
MgO	3.13	3.4	2.83
P ₂ O ₅	0.07	1.4	ND
SO ₃	2.61	2.03	0.58
ZrO ₂	0	0.47	0.27

The average particle size and chemical compositions of POBA, POCP, and OPC are listed in **Tables 3** and **4**, respectively. The particle of POCP was generally finer than POBA and OPC. Its D(u, 0.5) was less than half of POBA and OPC, and its specific surface area was 2.2 to 2.4 times greater than POBA and OPC (**Table 3**). The fineness of POBA was similar to OPC.

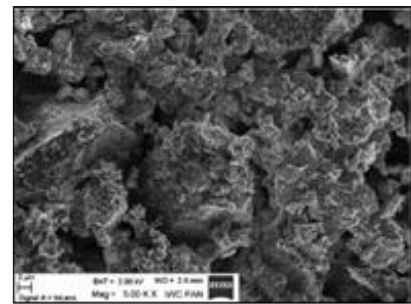
The porous structures of POBA and POCP, as observed in **Figure 3**, affected the materials' density and specific gravity. The POCP and OPC had fewer pores than POBA. Its density and specific gravity were high.



(a) Palm Oil Boiler Ash



(b) Palm Oil Clinker Powder



(c) Morphology of cement type I (Jozwiak-Niedzwiedzka, 2015)

Figure 3. Illustration of (a) POBA, (b) POCP, and (c) OPC microstructure kernel shells.

3.2. Fresh mortar

Figure 4 shows the flow behavior of the control mix and POBA-POCP blended mixes. The results showed that the addition of POBA and POCP as partial replacement of cement increased the flowability of fresh mortar. Similar behavior was observed by Ahmmad et al. (2017), whereby the slump value of concrete increased when POCP was added to the concrete. This was due to the high content of silica (**Table 4**) and dicalcium silicate (C2S) as the presence of wollastonites in POCP lowered the hydration rate at early stages (Ahmmad et al., 2017; Neville and Brooks, 1987). In addition, POBA

comprised high silica content. For that, the combination of POBA and POCP had boosted the flowability of blended cement mortar, which is important for the workability of concrete.

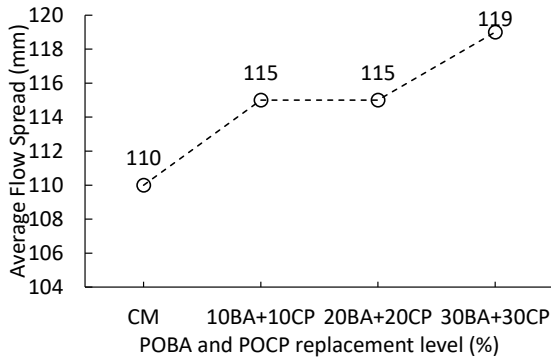


Figure 4. Flow spread of mortar.

3.3. Brick Properties

3.3.1 Density, Water Absorption, and Void Test

Figure 5 presents the bulk density of the bricks on days 7 and 28. Overall, the density of bricks decreased as the percentage of cement replacement increased.

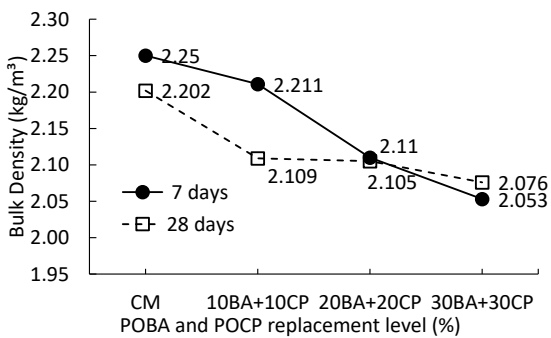


Figure 5. Bulk density of bricks.

In general, the brick density was affected by the void content and the material density. Macro and micro-voids were present in bricks due to the irregular shapes of POBA and POCP particles (Figure 3). However, the void content on day 28 was relatively low, which ranged between 3.6% and 3.72% (Figure 6). This

implied that the density of bricks was more significantly affected by the density and specific gravity of the material instead of the void content in the mix. The density and specific gravity of POBA and POCP were 52.7% and 28.6% lower than OPC (Table 2). Thus, the brick density ranged between 2 kg/m³ and 2.25 kg/m³.

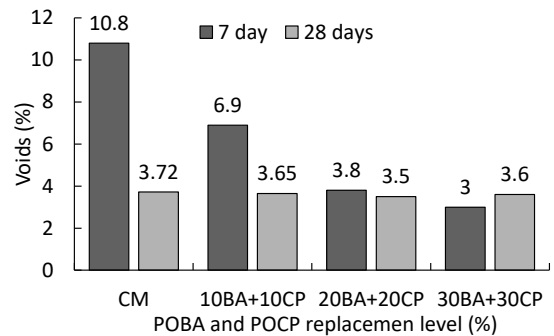


Figure 6. Voids volume in bricks.

The water absorption of bricks shown in Figure 7 indicates a slight increment as the replacement level increased. The water absorption for the bricks ranged from 1.66% to 1.75%. According to ASTM C62 (ASTM International, 2017), the water absorption of cement brick should be less than 7%, thus all bricks achieved the standard requirement.

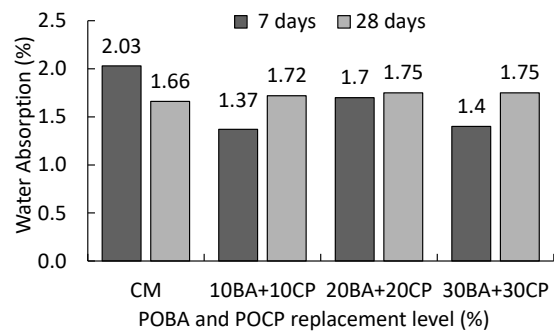


Figure 7. Water absorption of bricks.

3.3.2 Compressive strength

Table 5 shows that the optimum percentage of cement replacement was 20% as it yielded the highest compressive strength of the bricks. Figure 8 presents

the differences in the compressive strength between the modified bricks and the control mix. From the results, the replacement of 20% OPC with POBA and POCP increased 28.4% strength as compared with the control mix (CM). The compressive strength at 28-days for CM was 16.93 MPa whilst 20BA+20CP brick was 21.72 MPa. The minimum compressive strength of CM for no weathering (NW) brick is 10.3 MPa (ASTM International, 2017). According to Roslan et al. (2020), interfacial bonding between particles was affected by the contact surface area. The large surface area of POBA and POCP (Table 3) had enhanced the chemical reactivity of siliceous and aluminous components with calcium hydroxide to form compounds that possessed cementitious properties. This led to the increment of the brick’s compressive strength.

Table 5. Compressive strength of bricks (MPa).

Mixes	Day 7	Day 28
CM	11.27	16.93
10BA+10CP	13.33	17.10
20BA+20CP	14.47	21.72
30BA+30CP	9.43	13.93

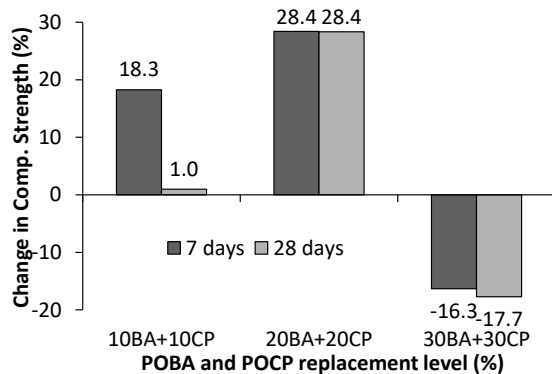


Figure 8. Changes in compressive strength of bricks.

There was a sudden drop of the compressive strength up to 17.7% for 30BA+30CP brick (Figure 8). According to Payá et al. (2001), pozzolanic materials with high porosity can affect the hardened

properties of the mix. The water added to the mixture would end up filling the pores of the particles, thus disrupt the hydration process.

The brick 20BA+20CP gave a compressive strength of 21.72 MPa, which was slightly higher than the minimum compressive strength of 20.7 MPa for severe weathering (SW) brick as required by ASTM C62. Thus, it could potentially be used as SW brick. Overall, 10BA+10CP, and 30BA+30CP bricks can be used as NW bricks as the bricks achieved the minimum strength of 10.3 MPa (ASTM C62).

3.4. Relationship between compressive strength and weight loss

The quantity of weight loss implied the rigidity of the brick against the compressive load. From Figure 9, both graphs (compressive strength on days 7 and 28) show an inversely proportional relationship between compressive strength and weight loss. This indicates that the increase of POBA and POCP (more than 20% replacement) affected the rigidity of the brick resulting it being more brittle. A good correlation between the two parameters was observed as the R-square for 7 and 28 days were 0.7758 and 0.8158, respectively. Figure 10 illustrates the failure mode of bricks at 28 days and the ruptures appeared to be more severe when cement replacement exceed 20%.

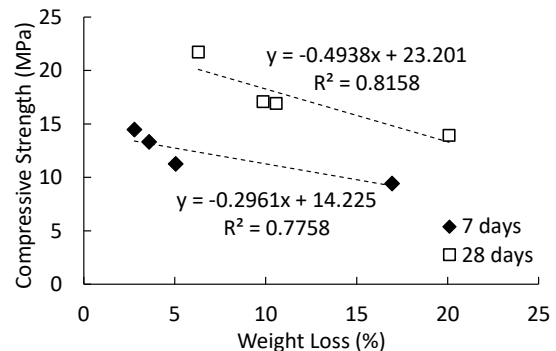


Figure 9. Relationship between compressive strength and weight loss.



Figure 10. Failure mode of bricks after compression

4. CONCLUSION

This study investigated the application of composite palm oil ashes (POBA

REFERENCES

- Abutaha, F., Abdul Razak, H., & Kanadasan, J. (2016). Effect of palm oil clinker (POC) aggregates on fresh and hardened properties of concrete. *Construction and Building Materials*, 112, 416–423. <https://doi.org/10.1016/j.conbuildmat.2016.02.172>
- Ahmmad, R., Alengaram, U.J., Jumaat, M.Z., Sulong, N.H.R., Yusuf, M.O., & Rehman, M.A. (2017). Feasibility study on the use of high volume palm oil clinker waste in environmental friendly lightweight concrete. *Construction and Building Materials*, 135, 94–103. <https://doi.org/10.1016/j.conbuildmat.2016.12.098>
- Ahmmad, R., Jumaat, M.Z., Alengaram, U.J., Bahri, S., Rehman, M.A., & Hashim, H.Bin. (2016). Performance evaluation of palm oil clinker as coarse aggregate in high strength lightweight concrete. *Journal of Cleaner Production*, 112, 566–574. <https://doi.org/10.1016/j.jclepro.2015.08.043>
- ASTM International (2017). ASTM C62-17, Standard Specification for Building Brick (Solid Masonry Units Made from Clay or Shale), 1-4.
- ASTM International (2015). ASTM C1437-15, Standard Test Method for Flow of Hydraulic Cement Mortar, 1-4.

and POCP) as partial cement replacement materials in cement brick. The two materials enhanced the flowability of the fresh mortar due to its high silica content. The densities and void content of bricks decreased as the percentage of cement replacement increased. It showed that the density of bricks was significantly affected by the density and specific gravity of POBA and POCP. The water absorption of bricks increased slightly as the replacement level increased. The water absorption was less than 7%, thus all bricks achieved the standard requirement.

From the results, the replacement of OPC with 20% POBA and 20% POCP increased 28.4% strength of the control mix. Brick 20BA+20CP had the potential to be used as severe weathering (SW) brick for meeting the minimum compressive strength set by ASTM C62.

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- Boey, P.L., Ganesan, S., Lim, S.X., Lim, S.L., Maniam, G.P., & Khairuddean, M. (2011). Utilization of BA (boiler ash) as catalyst for transesterification of palm olein. *Energy*, 36, 5791–5796. <https://doi.org/10.1016/j.energy.2011.09.005>
- British European Standard (2013). BS EN 12620-13, Aggregates for concrete. Pp. 1–60.
- Bukit, N., Ginting, E.M., Pardede, I.S., Frida, E., & Bukit, B.F. (2018). Mechanical properties of composite thermoplastic hdpe / natural rubber and palm oil boiler ash as a filler. *Journal of Physics: Conference Series*, 1120, 1–8. <https://doi.org/10.1088/1742-6596/1120/1/012003>
- Flatt, R.J., Roussel, N., & Cheeseman, C.R. (2012). Concrete: An eco material that needs to be improved. *Journal of the European Ceramic Society*, 32(11), 2787–2798. <https://doi.org/10.1016/j.jeurceramsoc.2011.11.012>
- Jóźwiak-Niedźwiedzka, D. (2015). Microscopic observations of self-healing products in calcareous fly ash mortars. *Microscopy Research and Technique*, 78(1), 22-29. <https://doi.org/10.1002/jemt.22440>
- Kajaste, R., & Hurme, M. (2016). Cement industry greenhouse gas emissions - Management options and abatement cost. *Journal of Cleaner Production*, 112, 4041–4052. <https://doi.org/10.1016/j.jclepro.2015.07.055>
- Kanadasan, J., & Razak, H.A. (2015). Utilization of palm oil clinker as cement replacement material. *Materials*, 8(12), 8817–8838. <https://doi.org/10.3390/ma8125494>
- Kanadasan, J., Razak, H.A., & Subramaniam, V. (2018). Properties of high flowable mortar containing high volume palm oil clinker (POC) fine for eco-friendly construction. *Journal of Cleaner Production*, 170, 1244–1259. <https://doi.org/10.1016/j.jclepro.2017.09.068>
- Karim, M.R., Hashim, H., & Abdul Razak, H. (2016). Thermal activation effect on palm oil clinker properties and their influence on strength development in cement mortar. *Construction and Building Materials*, 125, 670–678. <https://doi.org/10.1016/j.conbuildmat.2016.10.002>
- Karim, M.R., Hashim, H., Abdul Razak, H., & Yusoff, S. (2017). Characterization of palm oil clinker powder for utilization in cement-based applications. *Construction and Building Materials*, 135, 21–29. <https://doi.org/10.1016/j.conbuildmat.2016.12.158>
- Kow, K.W., Yi Mun, L., & Yusoff, R. (2015). Silica gel synthesized from oil palm boiler ash. *Journal of Mineral Metal and Material Engineering*, 1, 14–18.
- Lau, S. Y., Phuan, S. L., Danquah, M. K., & Acquah, C. (2019). Sustainable palm oil refining using pelletized and surface-modified oil palm boiler ash (OPBA) biosorbent. *Journal of Cleaner Production*, 230, 527–535. <https://doi.org/10.1016/j.jclepro.2019.04.390>
- Ling, J. H., Lim, Y. T., Leong, W. K., & Sia, H. T. (2021). Effects of Adding Silica Fume and Empty Fruit Bunch to the Mix of Cement Brick. *Indonesian Journal of Computing, Engineering, and Design*, 3(1), 19-30. <https://doi.org/10.35806/ijoced.v3i1.141>
- Ministry of Natural Resources and Environment Malaysia. (2014). A Roadmap of Emissions Intensity Reduction in Malaysia.

- Nayaka, R.R., Alengaram, U.J., Jumaat, M.Z., Yusoff, S.B., & Alnahhal, M.F. (2018). High volume cement replacement by environmental friendly industrial by-product palm oil clinker powder in cement-lime masonry mortar. *Journal of Cleaner Production*, 190, 272–284. <https://doi.org/10.1016/j.jclepro.2018.03.291>
- Nayaka, R.R., Alengaram, U.J., Jumaat, M.Z., Yusoff, S., & Sumesh, M. (2018). Influence of palm oil clinker powder on the fresh and mechanical properties of masonry mortars. *IOP Conference Series: Materials Science and Engineering*, 431(8). <https://doi.org/10.1088/1757-899X/431/8/082002>
- Neville, A. M., & Brooks, J. J. (1987). *Concrete Technology* (2nd ed.). United Kingdom: Pearson. <https://doi.org/10.6004/jnccn.2015.0201>
- Payá, J., Borrachero, M.V., Monzó, J., Peris-Mora, E., & Amahjour, F. (2001). Enhanced conductivity measurement techniques for evaluation of fly ash pozzolanic activity. *Cement and Concrete Research*, 31, 41–49. [https://doi.org/10.1016/S0008-8846\(00\)00434-8](https://doi.org/10.1016/S0008-8846(00)00434-8)
- Roslan, A., Mohamed Yusof, M.K.T., Sharipudin, S.S., Michael, Z., & SharulAzhar, I.I. (2020). Feasibility study of palm boiler ash as cement and sand replacement in concrete. *Journal of Engineering Science and Technology*, 15(4), 2361–2378.
- Yahya, Z., Abdullah, M.M.A.B., Hussin, K., Ismail, K.N., Razak, R.A., & Sandu, A.V. (2015). Effect of solids-to-liquids, Na₂SiO₃-to-NaOH and curing temperature on the palm oil boiler ash (Si + Ca) geopolymerisation system. *Materials*, 8, 2227–2242. <https://doi.org/10.3390/ma8052227>