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Utilization of Palm Oil Fuel Ash in Brick Manufacturing for Lightweight Fired Clay Brick Production

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Abstract: The utilization of palm oil fuel ash (POFA) into fired clay bricks is one of the alternatives for minimizing disposal of POFA waste in landfill. This study was conducted to investigate the effects of different percentages of POFA waste (0, 1, 5, 10, 20 and 30%) incorporated into fired clay bricks. The manufactured bricks were fired at 1050°C with heating rate of 1°C/min. The formulation of 20 and 30% of POFA brick (POFAB) was prepared as a comparative purpose. The manufactured bricks were tested in terms of chemical composition, geotechnical properties and physical mechanical properties of brick. The results showed that replacement 5% of POFA into fired clay bricks could yield lightweight fired clay brick due to the formation of porosity inside the brick, thereby reducing dry density of bricks. However, the replacement more than 10% of POFA resulted in a weak bonding between brick particles. In terms of compressive strength, the incorporation of 1 to 5% of POFA was found to be useful for non-loading applications. To conclude, POFA can potentially be utilized in the production of fired clay bricks to produce low-cost, lightweight and environmentally friendly building materials.

Keywords: fired clay brick, POFA, palm oil waste

1. Introduction

Palm oil plantations have become one of Malaysia's success stories in the agricultural sector. From humble beginnings in the early 1920s, the agricultural industry has since developed rapidly. Over half of the world's total palm oil today comes from the palm oil industry in Malaysia. Until December 2017, Malaysia had produced 20 million tons of palm oil on 5 million hectares of land (Malaysian Palm Oil Board, 2018). Therefore, these agricultural crops have become the foremost source of returns for the economy in Malaysia since time ancient.

As a result of the booming industry, thousands tons of palm oil mill waste are being produced annually by palm oil mills industries in Malaysia. A considerable amount of solid waste in the form of fibers, kernel shells and empty oil palm bunches are produced during palm oil processing (Awalluddin et al., 2015). According to Abdullah & Sulaiman (2013), problems associated with palm oil production is the large quantities of processed residues that have no economic value. These residues are often disposed of through illegal and uncontrolled open burning which is discouraged by the authorities. This problem tends to burden the operators with disposal difficulties and increased operating cost.

An example of waste generated by palm oil mill activities is palm oil fuel ash (POFA). Palm oil fuel ash (POFA), also known as an industrial byproduct, is another concern that arises from palm oil industries. POFA is a type of ash produced from husk fibers and shells during palm oil burning in the boiler (Ul Islam et al., 2015). Currently, shells and

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fiber wastes are widely used as fuel to produce steam in palm oil mills. However, after the combustion process, 5% of ashes are generated and they are directly dumped into open fields near the mills (Al Subari et al., 2018). This might result in smog on a humid day which can affect human health and traffic safety.

Recently, there has been increasing interest in the use of a variety of wastes to produce environmentally friendly and low-cost fired clay bricks. Brick is a masonry unit utilized as building materials due to its attributes (Adazabra, Viruthagiri, & Kannan, 2017). Fired clay bricks have been designed to be more homogenous, porous and stronger due to the ceramic bonding from the fusion phase of silica and alumina present in clay compositions (Adazabra, Viruthagiri, & Kannan, 2017; Bories et al., 2015; Barbieri et al., 2013; Demir, Baspinar, & Orhan 2005; Eliche-Quesada et al., 2011). Successful attempts have been made by previous researchers to incorporate spent shea (Adazabra, Viruthagiri, & Kannan, 2017), wheat straw, sunflower seed cake (Bories et al., 2015), sawdust, grape seed, sugarcane ash (Barbieri et al., 2013), processed waste tea (Demir, Baspinar, & Orhan 2005) and coffee ground (Eliche-Quesada et al., 2011) into fired clay bricks.

During preliminary investigation, it was discovered that incorporation of POFA from 20 and 30% had caused bricks to become weakening and brittle after firing. Therefore, based on the experimental work, several researchers have recommended that incorporation of waste in brick production is limited to 10% in order to reach a positive and negative equilibrium of physical and mechanical properties (Barbieri et al., 2013). The experimental work additionally has demonstrated that incorporation recycle waste could be environmentally advantageous but also increased the performance of brick properties. Therefore, POFA was collected and incorporated into fired clay bricks as an alternative solution to environmental problems. The utilization of wastes in clay bricks usually has a positive effect on its properties, although a decreased performance in certain aspects has also been observed.

2. Materials and Methods

2.1 Raw materials preparation and characterization

Clay soil was collected from a brick manufacturer located in Yong Peng, Johor. Palm oil fuel ash (POFA) was taken from a palm oil mill at Kluang, Johor. Upon delivery, both clay soil and POFA were oven dried at 105°C for 24 hours to remove the initial moisture. The clay soil and POFA were then filtered through a 4.75 mm sieve and retained on a 2.36 mm nominal sieve as shown in Fig. 1a and Fig. 1b. The chemical compositions of the raw materials were analyzed using X-Ray Fluorescence (XRF). Meanwhile, X-Ray Diffraction (XRD) was conducted to analyze the mineralogical phases in raw materials. Paste powder was placed in a sample holder and flattened using a glass slide. The XRD was carried out using D8, Bruker with Cu Kα radiation in the range of 10° to 90° and a scan angle of 0.02°

The microscopy image of raw materials used in this study was analyzed using Hitachi HORIBA Integrated Analysis System (SEM/EDX Series). The image sample was shot using magnification between 100x to 3000x. In order to measure the changes in material mass when subjected to temperature, raw materials were analyzed using thermogravimetric analysis and differential thermal analysis (TGA-DTA). The maximum temperature was set to 1050°C with a scan rate of 1°C/min.

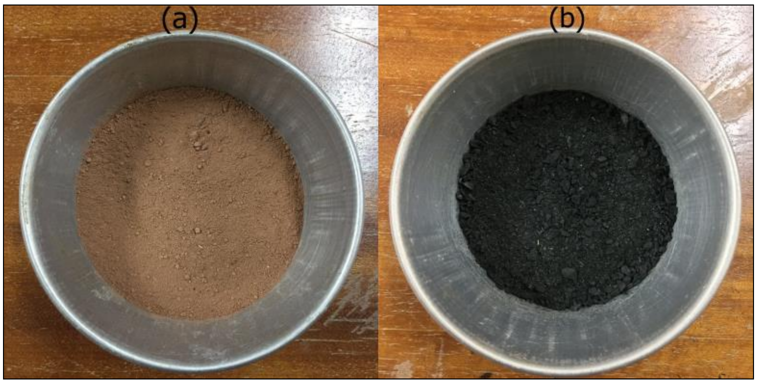


Fig. 1 - (a) Raw clay soil; (b) Palm oil fuel ash.

2.2 Chemical and geotechnical properties

Geotechnical test measuring specific gravity, liquid limit, plastic limit and plasticity index were performed according to BS 1377-2 (British Standard Institution, 1990a) while the loss of ignition test was conducted according to BS 1377-3 (British Standard Institution, 1990b). POFA was sent to Kualiti Alam for calorific value analysis.

During brick manufacturing process, a necessary amount of water was added to achieve adequate plasticity of the mixture as well as to minimize cracking during drying and firing processes. This test was performed according to the

Standard Proctor Test (British Standard Institution, 1990c). The first series of the compaction test was conducted with raw clay soil to determine clay soil compaction, followed by clay soil mixed with a predetermined mass of POFA.

2.3 Brick manufacturing process

The calculated quantities of POFA were added to the clay soil in percentages of 1%, 5% and 10%. The selection of these ratios was based on previous experience in which the incorporation above 10% of waste resulted in poor physical and mechanical properties (Barbieri et al., 2013). Thus, these ratios are considered optimal.

As shown in Table 1, the bricks were manufactured according to industrial standard processes clay soil and POFA sample were first mixed with a predetermined quantity of water (Fig. 2a). The mixture was then pressed into moulds measuring 215 mm x 102.5 mm x 65 mm with a pressure of 2000 psi (Fig. 2b). The prepared bricks were kept for 24 hours at room temperature (Fig. 2c), followed by an oven drying period of 24 hours at 105°C (Fig. 2d). The dried bricks were finally fired in a furnace with heating rates of 1°C/min at 1050°C (Fig, 2e). Fig. 2f shows POFAB after the firing stage was completed.

In addition, control bricks were also prepared in this study. The manufactured bricks which were used as Control Brick (CB) for brick without POFA waste, POFAB1%, POFAB5% and POFAB10% for brick with 1%, 5%, and 10% of POFA waste, respectively.

The manufactured clay bricks then underwent a series of test including physical, mechanical properties such as firing shrinkage, dry density, initial rate of absorption (IRA) (British Standard Institution, 2011a), water absorption (British Standard Institution, 1998), porosity and compressive strength (British Standard Institution, 2011b).

Table 1 - Mixture design of manufactured brick.

Mixture identification	Clay (*g*)	POFA (*g*)	Water *(mL)*
CB	2800	0	476
POFAB1%	2780	20	493
POFAB5%	2700	100	524
POFAB10%	2590	210	557

(a) (b) (c)

(d) (e) (f)

Fig. 2 - (a) Mixing soil and POFA with predetermined water; (b) Compress in brick machine; (c) Drying at room temperature; (d) Drying in ventilated oven; (e) Firing in laboratory furnace; (f) POFAB after firing

3. Results and Discussion

3.1 Characterization of raw materials

Chemical composition of raw materials was measured using the XRF technique and listed in Table 2. Clay soil presents a typical composition of SiO_2 (55.7%), Al_2O_3 (24.4%) and Fe_2O_3 (4.46%) with minor content of Na_2O (0.30%), CaO (0.25%) and MnO (1.20%). Major constituents in this study are consistent with previous studies where practical amount of silica and alumina in clay soil are ideal for the manufacture of high quality bricks (ILO, 1984). Due to low CaO and rich in silica-alumina content, clay soil in this study can be categorized as non-calcareous clay (El Ouahabi et al., 2015). In addition, large amount of ferric oxide frequently contributes to the reddish colour of brick after firing process.

The main chemical compositions of POFA were SiO_2 (54.7%), CaO (8.8%) and Fe_2O_3 (5.89%) with minor of Na_2O (0.30%) and MnO (0.25%). High silica content in POFA contributes to the pozzolanic reactions which increases the bonding between clay particles during brick preparation (Pourakbar et al., 2015; Oyeleke et al., 2011). In addition, POFA can be incorporated into fired clay brick due to the clay flexibility and hence the final results are still within the standard limit.

Table 2 - Chemical composition of raw materials.

Mixture identification	Clay (*g*)	POFA (*g*)
SiO_2	55.7	54.70
Al_2O_3	24.4	4.32
Na_2O	0.30	0.30
K_2O	2.24	5.70
Fe_2O_3	4.46	5.89
CaO	0.25	8.80
MgO	1.20	4.34
TiO_2	0.94	n.d
MnO	0.04	1.20
PbO	n.d	1.75
ZnO	n.d	1.48
n.d : not detectable		

From Fig. 3, the first two peaks of quartz (SiO_2) were recorded at 20.8° and 26.6° 2θ respectively, which represent major crystal structure in clay soil. As reported in previous studies, quartz is the most dominant mineral present in clay structure (Akinship & Kornelius, 2017; Ingham, 2013). Meanwhile, minor mineral peaks recorded at 12.3° 2θ, 33.1° 2θ and 19.8° 2θ were kaolinite ($Al_2(SiO_5(OH)_5$, hematite (Fe_2O_3) and muscovite ($KAl_2(Si_3AlO_{10})(F,OH)_2$), respectively. Hematite formation suggested by the existence of iron oxide, which has an influence on reddish brick colour (ILO, 1984; Mueller et al., 2008). Meanwhile, kaolinite and muscovite are typically found in clay as natural minerals.

The structural analysis of POFA is shown in Fig. 4. Similar to clay soil, POFA was dominated by quartz (SiO_2), detected at peak of 26.6° 2θ. Besides quartz, cristobalite (SiO_2), magnetite (Fe_2O_4), calcite ($CaCO_3$) and berlinite (AlO_4P) were also been found. At peak 43.4° 2θ, cristobalite is expected to derive from the modification of silica leading to fibres and shells burning in the boiler (Zarina et al., 2013). Meanwhile, the presence of magnetite is due to the reduction of hematite from iron oxide during heating process, as reported by previous researchers (Abdul Rashid et al., 2014).

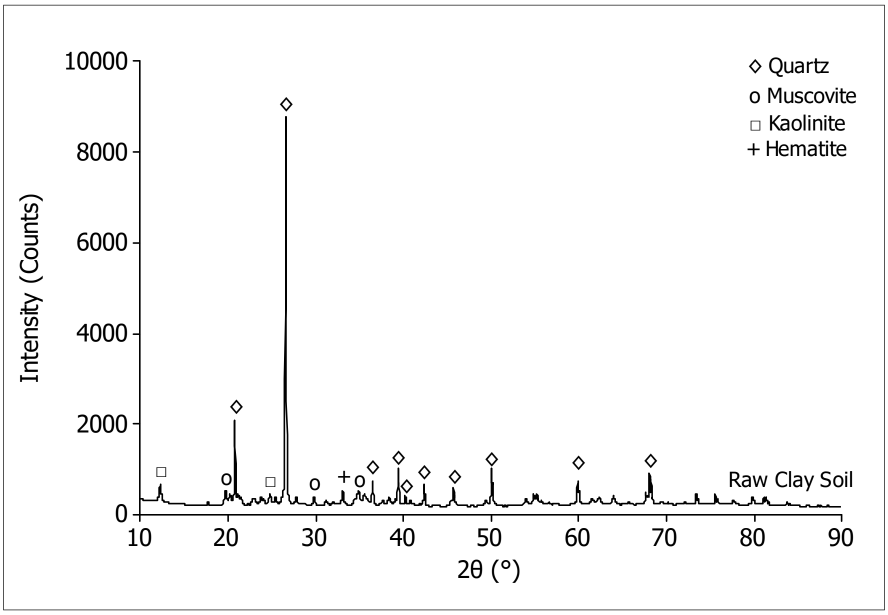


Fig. 3 - XRD pattern of clay soil

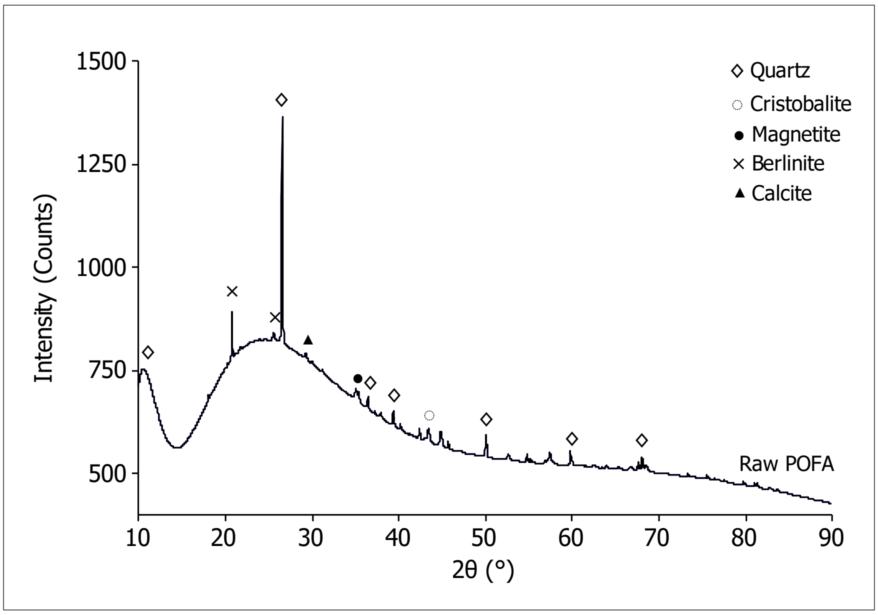


Fig. 4 - XRD pattern of POFA

3.2 Scanning electron microscope of raw materials

The microscopy image of clay soil is presented in Fig. 5a. From the image, it can be observed that shape of clay soil particles is irregular with rough surface. Particle size of the clay soil ranged from 0.002 to 0.055 mm. These sizes are helpful in increasing the plasticity properties that prevent increased shrinkage during drying process. Meanwhile, EDX of clay soil revealed that carbon (C), oxygen (O), silica (Si), aluminium (Al), iron (Fe) and potassium (K) present with 8.95, 42.12, 27.66, 15.27, 3.11 and 2.89%, respectively. The finding from EDX spectrum is consistent with the chemical composition of clay soil derived from XRF analysis in Section 3.1.

On the other hand, Fig. 6a shows the microscopy image of POFA. The image showed that POFA was irregular in shape and had a porous texture (Zarina et al., 2013; Jamo, Noh, & Ahmad, 2013; Raut & Gomez, 2017). The EDX spectrum in Fig. 6b indicates that the elements found in POFA contain oxygen (O), carbon (C), silica (Si), aluminium (Al), iron (Fe), calcium (Ca) and phosphorus (P) with 32.15, 25.44, 21.13, 12.61, 4.89, 2.15 and 1.63%, correspondingly. The findings from EDX are reliable with the chemical composition of POFA during XRF analysis.

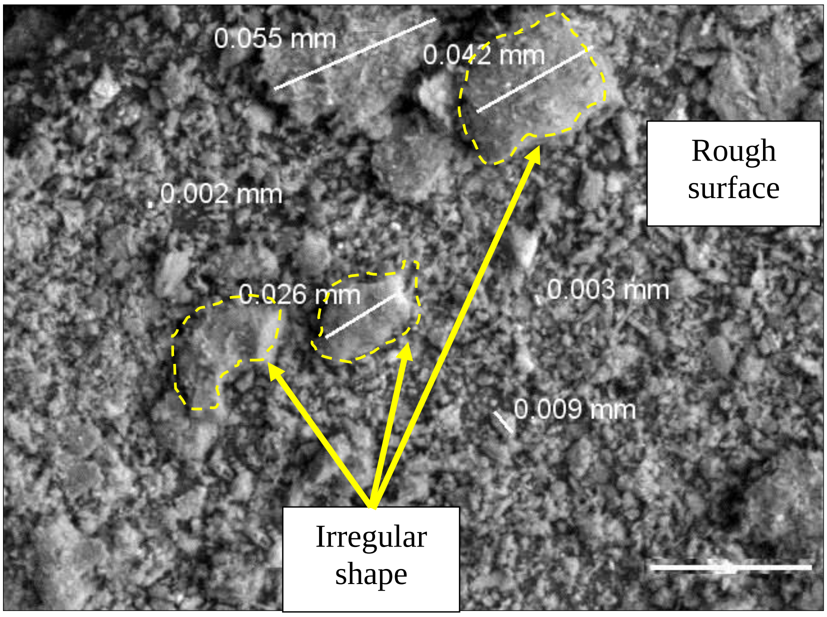
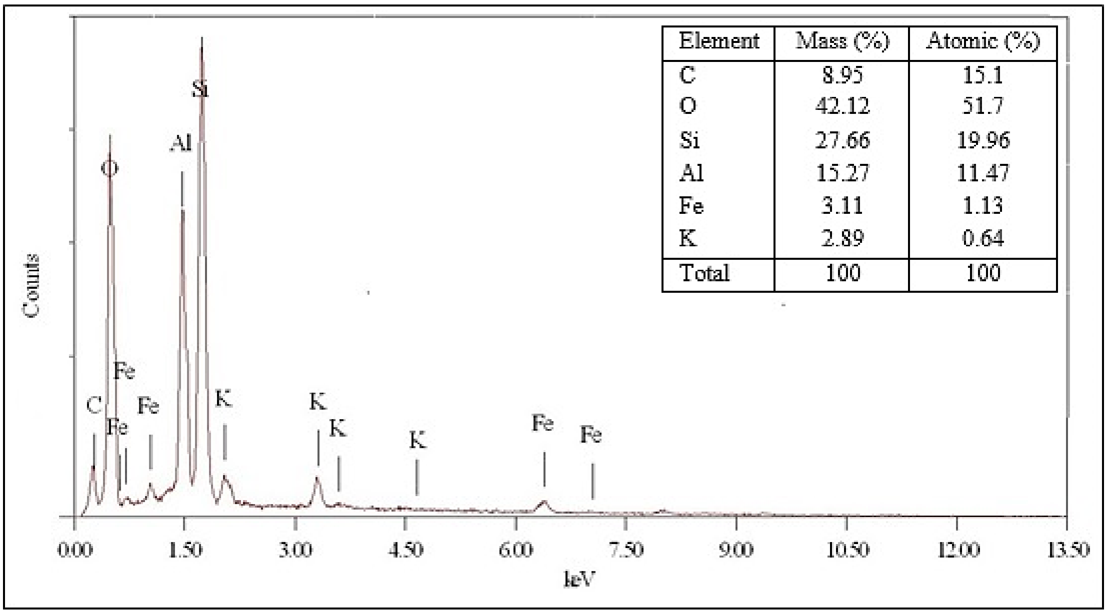


Fig. 5a- SEM image of clay soil



Element	Mass (%)	Atomic (%)
C	8.95	15.1
O	42.12	51.7
Si	27.66	19.96
Al	15.27	11.47
Fe	3.11	1.13
K	2.89	0.64
Total	100	100

Fig. 5b- EDX spectrum of clay soil

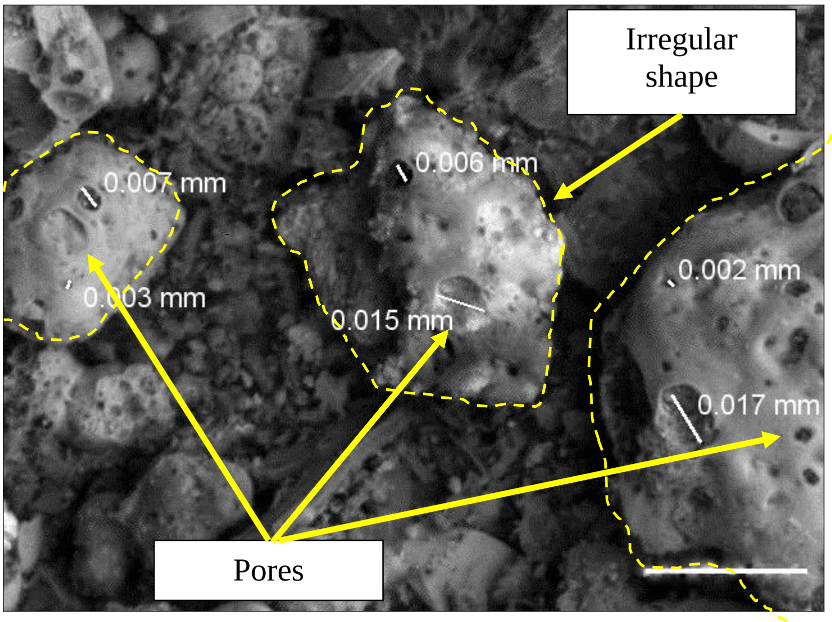
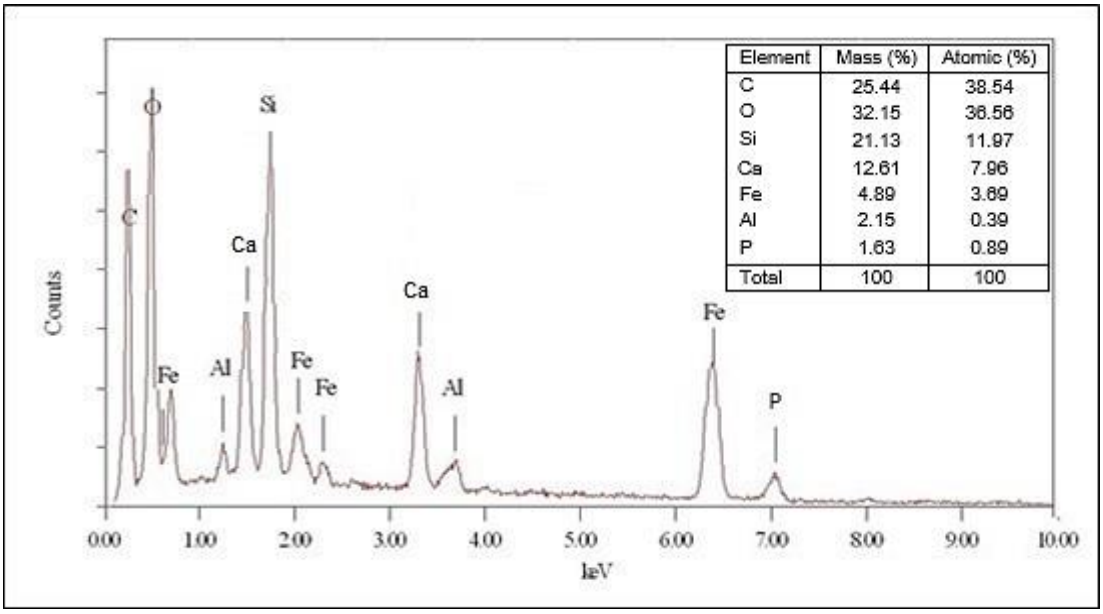


Fig. 6a- SEM image of POFA



Element	Mass (%)	Atomic (%)
C	25.44	38.54
O	32.15	36.56
Si	21.13	11.97
Ca	12.61	7.96
Fe	4.89	3.69
Al	2.15	0.39
P	1.63	0.89
Total	100	100

Fig. 6b- EDX spectrum of POFA

3.3 TGA-DTA analysis of raw materials

During the firing process, several reactions can be observed through TGA-DTA curve. According to Fig. 7, TGA curve of clay soil shows a total weight loss of 1.1 mg (5% decomposed). During the first stage, an endothermic reaction occurred at peak 37.5°C (between 20°C to 261.9°C) associated with the water evaporation from clay body (a weight loss of approximately 0.4 mg) (Monteiro et al., 2008). During the second stage, an exothermic reaction takes place at peak of 404.1°C, associated with the oxidation of organic matter and dehydroxylation of clay minerals. This resulted in weight loss of approximately 0.7 mg (between 261.9°C to 685.9°C) (Eliche-Quesada et al,. 2002). In this range, organic matter starts to burn and released significant pollutants such as carbon monoxide and carbon dioxide (Ramachandran, 2002); Rathossi & Pontikes, 2010).

Fig. 8 displayed TGA-DTA curve of POFA. The total weight loss for POFA was 12.55 mg (83% decomposed). In the first stage, an endothermic reaction takes place at peak of 63.5°C due to the elimination of water (a weight loss of 2.8 mg). As the temperature rose, there was an endothermic reaction occurred at peak of 420.9°C (weight loss of 15.35

mg). This can be attributed to the decomposition of organic matter and the thermal pattern is similar discovered by Hafizah et al., (2015).

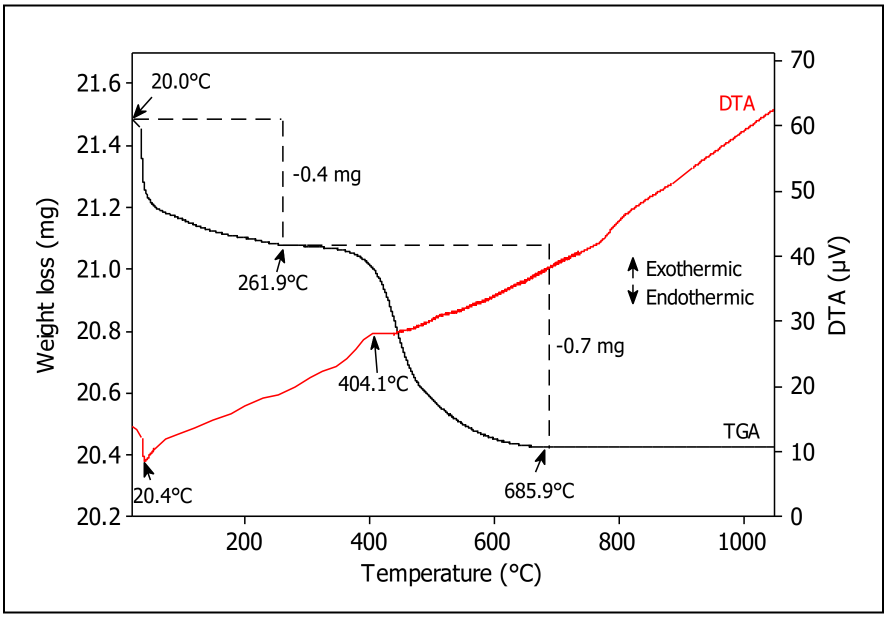


Fig. 7- TGA-DTA analysis of clay soil

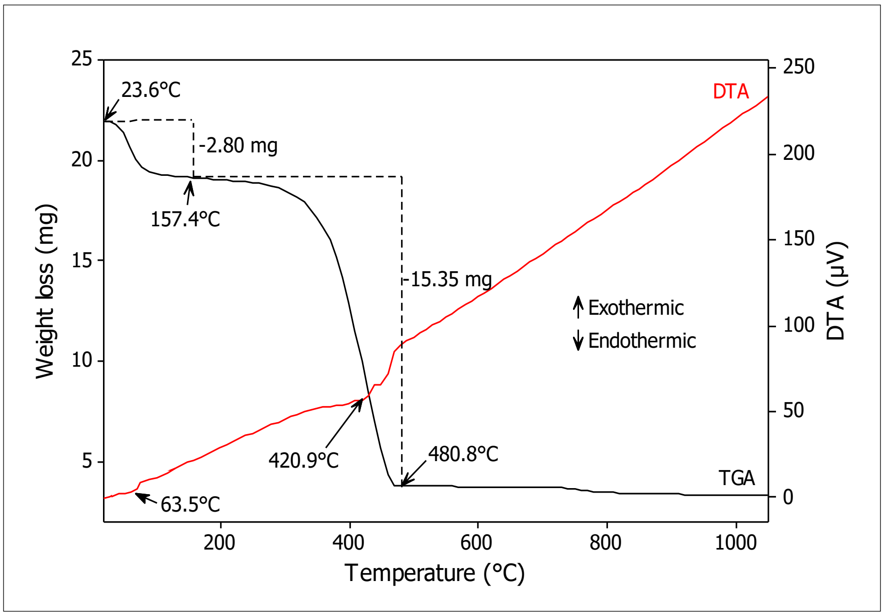


Fig. 8- TGA-DTA analysis of POFA

3.4 Geotechnical properties of raw materials

The physical characteristics of raw materials used in this study are shown in Table 3. The specific gravity of POFA (1.76) is lower than clay soil (2.56), suggesting that POFA contains high porous structure which subsequently lower their specific density (Oyeleke et al., 2011). As predicted, SEM image of POFA in Fig. 6a indicates the presence of pores on surface. Hence, incorporation of POFA into fired clay bricks will therefore reduce the weight of bricks.

From Table 3, liquid limit and plastic limit of clay soil were reported as 29.9 and 14.6%, respectively. The plasticity index was calculated as 15.3%, indicating that clay soil used in this study was silty clay. This clay shows low plasticity due to a low plastic limit, which is not essential for developing plasticity during the mixing process. According to the previous studies, selection of high plasticity clay soil for producing bricks would make it easier during extrusion and simultaneously increase homogeneity when it encounters water (Johari et al., 2011; Ukwatta et al., 2016).

The values of loss of ignition (LOI) for clay soil and POFA were reported as 1.92 and 4.95%, respectively. LOI of POFA is considered high due to the incomplete combustion of organic matter (Pourakbar et al., 2015). Meanwhile, the relationship between maximum dry density (MDD) and optimum moisture content (OMC) in Fig. 9 shows the incorporation of POFA from 1 to 10% significantly reduced MDD values while increasing OMC value. The increased in OMC values is attributed to the lower density of POFA. As expected, POFA has a porous structure capable of absorbing more water than clay soil particles during compaction test (Jamo, Noh, & Ahmad, 2013).

Table 3 - Physical Characteristic of raw materials.

Parameter	**Clay (*g*)**	**POFA (*g*)**
Specific gravity, Gs	2.56	1.76
Atterberg Limit Test		
Liquid limit, w_l (%)	29.9	n.a
Plastic limit, w_p (%)	14.6	n.a
Plasticity index, I_p (%)	15.3	n.a
Standard Proctor Test		
OMC (%)	17.0	17.6-19.9
MDD, ρ_{Dmax} (g/cm^3)	1.75	1.74-1.66
Loss of ignition, LOI (%)	1.92	4.95

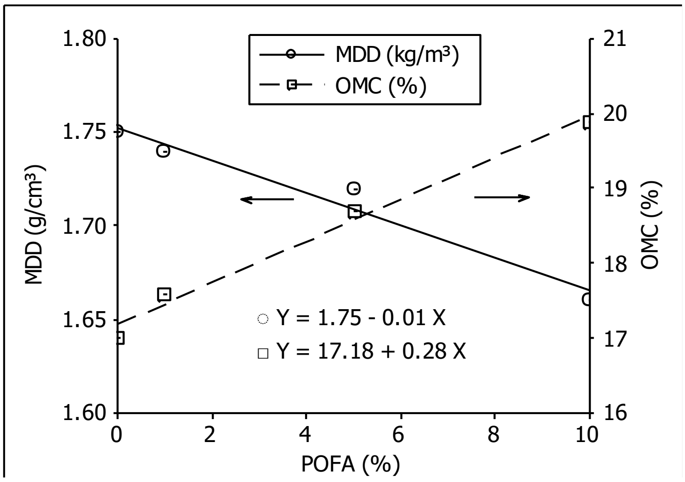


Fig. 9- Relationship of MDD and OMC

3.5 Properties of manufactured brick

Firing shrinkage of manufactured brick is shown in Fig. 10. From the figure, firing shrinkage varies from 0.3 to 0.9% depending on the POFA content. As the POFA increases, firing shrinkage of manufactured bricks also increased. POFAB10% showed higher firing shrinkage value with 67% difference compared to control bricks due to the large amount of waste inclusion along with the high-water intake. This can be explained by the presence of pores on POFA surface which absorb more water during the mixing stage. As a result, more water is removed during the drying and firing stage (Kizinievič, Kizinievič, & Malaiškienė, 2018). Therefore, POFAB10% appears to shrink more compared to other bricks. According to the standard, firing shrinkage is recommended to fall within 2.5 to 4% (BIA, 1992). The results showed that firing shrinkage values for all manufactured bricks were below the requirements. Good bricks have therefore been made.

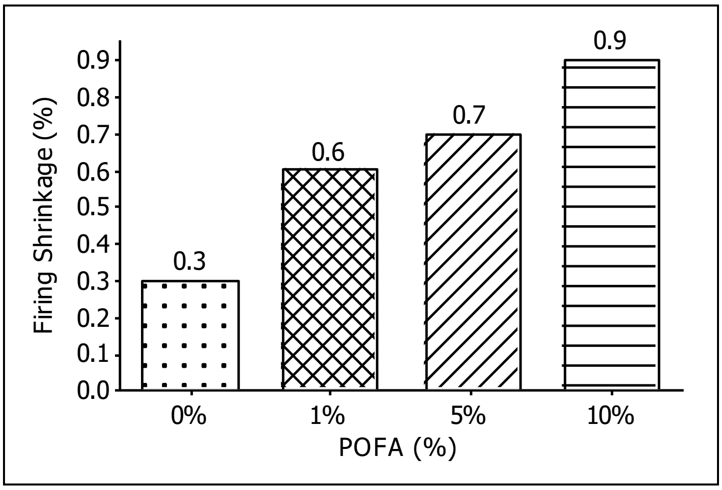


Fig. 10- Firing shrinkage of brick

Dry density of manufactured brick is presented in Fig. 11. From the figure, density values varied from 1599 to 1799 kg/m^3 depending on the POFA content. As the POFA increases, dry density of bricks decreased by a difference of 13% compared to control bricks. The density was anticipated to decrease due to the organic matter completely burnt at high temperature during the firing process. This can be explained by exothermic and endothermic reactions in Fig. 8 where almost 83% of POFA had decomposed close to 500°C, thus reducing weight of bricks (Hafizah et al., 2015). BS EN 771-1 (British Standard Institution, 2011a) specified that low gross dry density (LD) unit should have gross dry density less than or equal to 1000 kg/m^3 while high gross dry density (HD) unit should have gross dry density greater than 1000 kg/m^3. Results have shown that density of manufactured bricks can be classified using HD units. A lower brick density is preferred to reduce load during construction work as well as reducing logistic costs (Kadir and Mohajerani, 2015; Celik, Depsi, & Kılıc, 2014). The incorporation of POFA into fired clay bricks could therefore be useful for producing lightweight bricks.

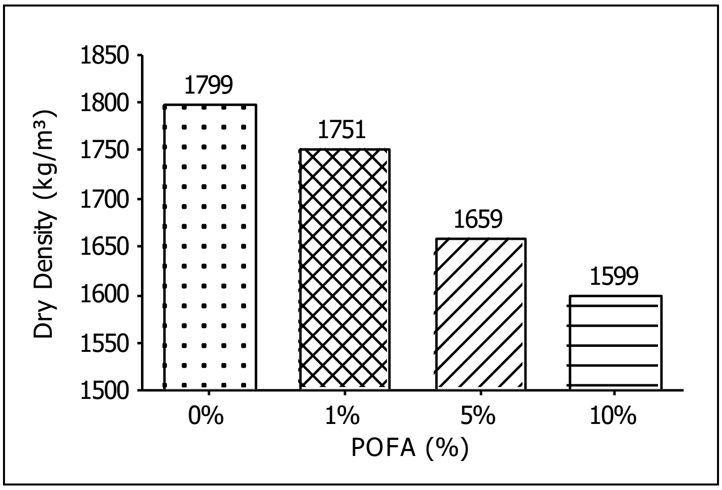


Fig. 11- Dry density of brick

Initial rate of absorption (IRA) of manufactured bricks is presented in Fig. 12. From Fig. 12, it can be observed that IRA values vary from 1.3 to 6.2 kg/m^2.min depending on the POFA content. When the POFA content increases, IRA of manufactured bricks also increased by a difference of 79% compared to control brick. The incorporation 10% of POFA into clay bricks increased the number of pores inside brick body and eventually allowed more water to seep through the brick (Zarina et al., 2013). Moreover, porosity results in Fig. 14 also proved that porosity increased by 20% with 10% of waste inclusion, which further increases IRA rates. The standard recommended that IRA should be lower than 2 kg/m^2.min. Nevertheless, the results obtained in this study were not very promising when IRA reached the acceptable limit, except for control bricks. Therefore, bricks should be soaked 3 to 24 hours before to prevent weak bonding between brick and mortar (British Standard Institution, 2011a).

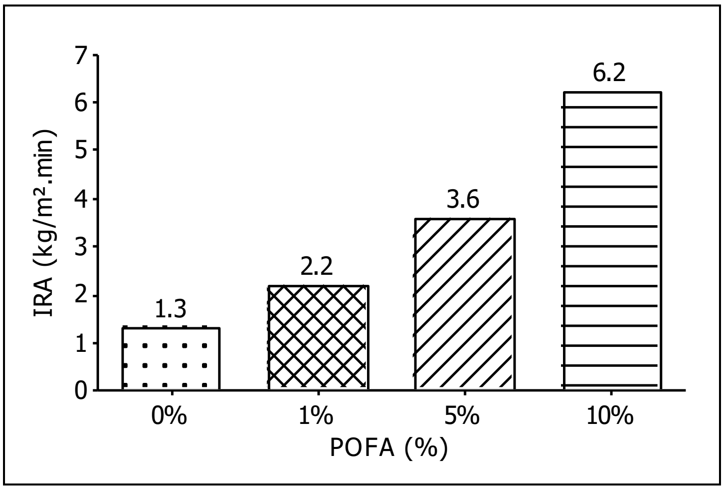


Fig. 12 - Initial rate of absorption of the brick

Water absorption of manufactured bricks is presented in Fig. 13. Water absorption values varied from 3 to 9% depending on the POFA content. As the POFA content increases, water absorption of manufactured bricks also increased. Brick incorporated with 10% of POFA showed high water absorption with 67% difference compared to control bricks. This phenomenon can be explained by testing mechanism. During the boiling period, air within pore space is replaced by steam which eventually changes to water during cooling period. As a result, the pressure in the pore space is lowered (Wilson, Carter, & Haff, 1999). This lower pressure forces water to absorb into numerous pores due to atmospheric pressure, thereby increasing water content inside the brick. Manufactured bricks in this study were found exceeded the limit of ≤ 4.5% and ≤ 7.0% by mass except for control bricks. Thus, these bricks can be used for non-loading purposes only. The incorporation 10% of POFA into clay brick increases porosity by 20%, causing water absorption to increase tremendously. However, the trends of water absorption in this study were found consistent with previous findings (Silva et al., 2017; Sicakova, Draganovska, & Kovac, 2017).

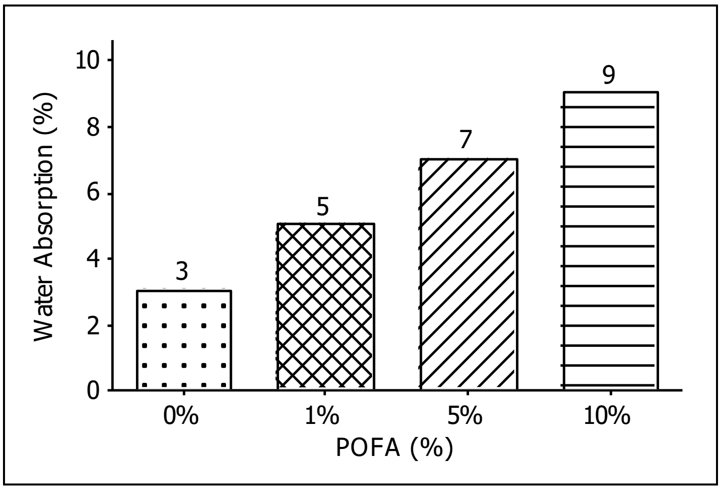


Fig. 13 - Water absorption of the brick

Porosity of manufactured brick is presented in Fig. 14. From the figure, porosity varied from 13 to 20% depending on POFA contents. As the POFA content increases, porosity of manufactured bricks also increased. The results showed that incorporation 1 to 10% of POFA has increased porosity with 35% difference compared to control brick. High porosity can be explained by the addition of organic matter inside the brick which is easily burnt at high temperature during the firing process (Zarina et al., 2013). The presence of pores is beneficial in reducing the density and thermal conductivity of brick. The findings observed in this study are comparable to previous study, suggesting that the incorporation of organic waste could increase porosity up to 50% (Kizinievič, Kizinievič, & Malaiškienė, 2018; Jordán et al., 2014).

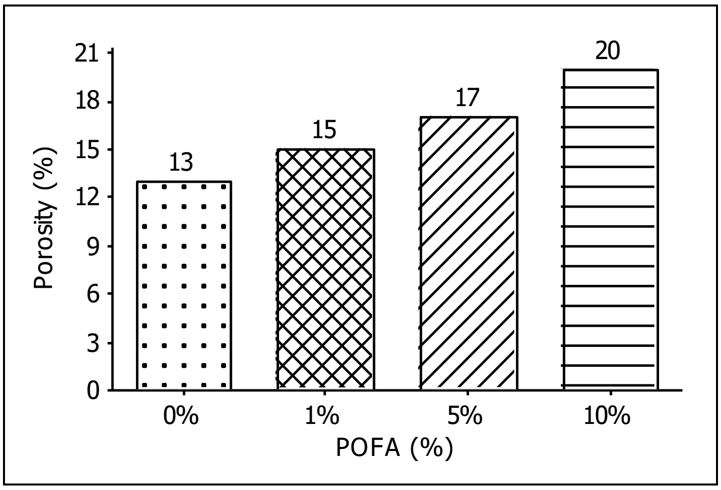


Fig. 14 - Porosity of the brick

Compressive strength of manufactured bricks is presented in Fig. 15. Compressive strength values ranged from 6.2 to 24.6 MPa depending on the POFA content. As the POFA increases, compressive strength also decreased by 74% compared to control bricks. The decline in strength was due to the weakening bonds between the brick particles. This was caused by the disintegration of organic materials during firing stage, as reported by Kazmi et al., (2016). Besides disintegration effects, the decrease in brick strength was also affected by porosity. In accordance with the present data, Šveda has demonstrated that increased pore volume or total porosity significantly reduces compressive strength of brick (Šveda, 2007). The results demonstrated that manufactured bricks in this study can be used as moderate-weather-resistant bricks (≥ 17.2 MPa), loading bearing walls 1 and 2 (≥ 7 and ≥ 14 MPa), non-loading bearing partitions (≥ 1.4 MPa) and load-bearing internal walls (≥ 5.2 MPa) (ASTM International, 2017; MS 76, 1972).

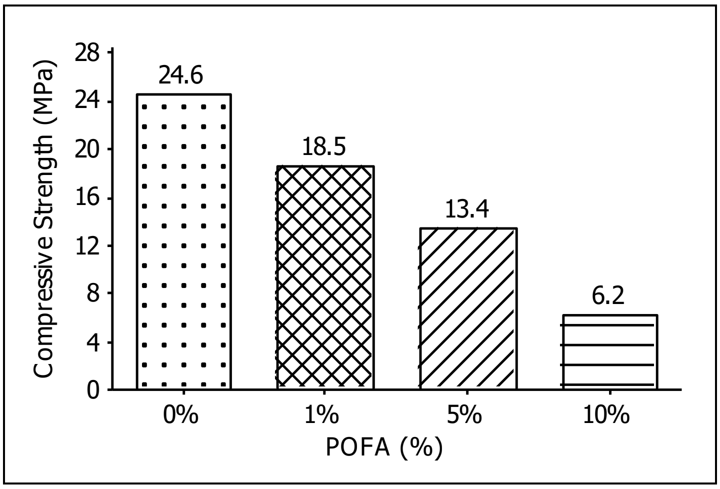


Fig. 13 - Compressive strength of the brick

4. Summary

In the early stages, several additional mixtures were formulated for 20 to 30% of POFA waste for comparative purposes. Furthermore, since the brick is inert, the incorporation of more than 10% of POFA waste led to weak bonding between clay soil and POFA particles. Therefore, the incorporation of POFA waste into clay bricks is restricted to a maximum of 10%.

In terms of physical and mechanical properties, the replacement of up to 5% of POFA was considered to be the optimal composition for brick production as it enhanced certain properties of bricks with acceptable limitations. Therefore, from a technical point of view, the production of bricks incorporated with POFA is a feasible solution. This offers some benefits such as reduced density and increased porosity, resulting in the development of lightweight fired clay brick. This would help reduce labour load during construction work. In comparison, fired clay bricks incorporated with 1 to 5% of POFA are ideal for non-loading applications or external works. In conclusion, the incorporation of POFA waste from palm oil mill industry into fired clay bricks appears to be a potential solution to waste disposal problems in landfills.

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References

Abd Rashid, R. Z., Mohd. Salleh, H., Ani, M. H., Yunus, N. A., Akiyama, T & Purwanto, H. (2014). Reduction of low grade iron ore pellet using palm kernel shell. Renewable Energy, 63, 617-623.

Abdullah, N. & Sulaiman, F. (2013). The oil palm wastes in Malaysia. In Matovic, M. D. (Eds.), Biomass now - sustainable growth and use (pp. 75-100). Canada: InTech.

Adazabra, A. N. N., Viruthagiri, G. & Kannan, P. (2017). Influence of spent shea waste addition on the technological properties of fired clay bricks. Journal of Building Engineering, 11, 166-177.

Akinship, O & Kornelius, G. (2017). Chemical and thermodynamic processes in clay brick firing technologies and associated atmospheric emissions metrics - A review. Journal of Pollutant Effects & Control, 5, 1-12.

Alsubari, B., Shafigh, P., Ibrahim, Z. & Jumaat, M. Z. (2018). Heat-treated palm oil fuel ash as an effective supplementary cementitious material originating from agriculture waste. Construction Building Materials, 167, 44-54.
ASTM International. (2017). C62-17. Standard specification for building brick (solid masonry units made from clay or shale), 10-13.

Awalludin, M. F., Sulaiman, O., Hashim, R. & Nadhari, W. N. A. W. (2015). An overview of the oil palm industry in malaysia and its waste utilization through thermochemical conversion, specifically via liquefaction. Renewable and Sustainable Energy Reviews, 50, 1469-1484.

Barbieri, L., Andreola, F., Lancellotti, I. & Taurino, R. (2013). Management of agricultural biomass wastes: preliminary study on characterization and valorisation in clay matrix bricks. Waste Management, 33 (11), 2307-15.
BIA. (1992). Technical notes 3A - Brick masonry material properties. Technical Notes on Brick Construction.

Bories, C., Aouba, L., Vedrenne, E. & Vilarem, G. (2015). Fired clay bricks using agricultural biomass wastes: study and characterization. Construction and Building Materials, 91, 158-163.

British Standard Institution. (1990a). BS 1377-2. Methods of test for soils for civil engineering purposes, Part 2: Classification tests. British Standard.

British Standard Institution. (1990b). BS 1377-3. Methods of test for soils for civil engineering purposes - Part 3: Chemical and electro-chemical tests. British Standard.

British Standard Institution. (1990c). BS 1377-4. Methods of test for soils for civil engineering purposes - Part 4: Compaction-related tests. British Standard.

British Standard Institution. (1998). BS EN 772-7. Methods of test for masonry units - Part 7: Determination of water absorption of clay masonry damp proof course units by boiling in water. British Standard.

British Standard Institution. (2011). BS EN 771-1. Specification for masonry units - Part 1 : Clay masonry units. British Standard.

British Standard Institution. (2011a). BS EN 772-1. Methods of test for masonry units - Part 1 : Determination of compressive strength. British Standard.

British Standard Institution. (2011b). BS EN 772-11. Methods of test for masonry units - Part 11 : Determination of water absorption of aggregate concrete, manufactured stone and natural action and the initial rate of water absorption of clay masonry units. British Standard.

Celik, A. G., Depci, T. & Kılıc, A. M. (2014). New lightweight colemanite-added perlite brick and comparison of its physicomechanical properties with other commercial lightweight materials. Construction and Building Materials, 62, 59-66.

De Bonis, A., Cultrone, G., Grifa, C., Langella, A., Leone, A. P., Mercurio, M. & Morra, V. (2017). Different shades of red : the complexity of mineralogical and physico- chemical factors in fluencing the colour of ceramics. Ceramics International, 43, 8065-8074.

Demir, I., Serhat Baspınar, M. & Orhan, M. (2005). Utilization of kraft pulp production residues in clay brick production. Building Environment, 40, 1533-1537.

El Ouahabi, M., Daoudi, L., Hatert, F. & Fagel, N. (2015). Modified mineral phases during clay ceramic firing. Clays and Clay Minerals, 63 (5), 404-413.

Eliche-Quesada, D., Martínez-Martínez, S., Pérez-Villarejo, L., Iglesias-Godino, F. J, Martínez-García, C. & Corpas-Iglesias, F. A. (2012). Valorization of biodiesel production residues in making porous clay brick. Fuel Processing Technology, 103, 166-173.

Eliche-Quesada, D., Pérez-Villarejo, L., Iglesias-Godino, F. J., Martínez-García, C. & Corpas-Iglesias, F. A. (2011). Incorporation of coffee grounds into clay brick production. Advances in Applied Ceramics, 110 (4), 225-232.

Hafizah, A. K. N., Hussin, M. W., Ismail, M., Bhutta, M. A. R., Azman, M., Ramadhansyah, P.J., Nur Farhayu, A. & Nor Hasanah, A. S. L. (2015). Potential effect of palm oil fuel ash as micro-filler of polymer concrete, Proceedings of the International Conference on Global Sustainability and Chemical Engineering, Kuala Lumpur, Malaysia, 41-49.

ILO. (1984). Small Scale Brickmaking. International Labour Office.

Ingham, P. (2013). Chapter 9-Bricks, terracotta, and other ceramics, In geomaterials under the microscope (pp. 163-17). United Kingdom: Academic Press.

Jamo, H. O., Noh, M. Z & Ahmad, Z. A. (2013). Structural analysis and surface morphology of a treated palm oil fuel ash. Prosiding Seminar Kebangsaan Aplikasi Sains dan Matematik. Johor, Malaysia, 65-70.

Johari, I., Jaya, R. P., Said, S. & Bakar, B. H. A. (2011). Chemical and physical properties of fired-clay brick at different type of rice husk ash, International Conference on Environment Science and Engineering, Bali, Indonesia, 8, 171-174.

Jordán, M. M., Pardo, F., Sanfeliu, T & Meseguer, S. (2014). Ceramic behaviour of some clay deposits from Guayas province, Ecuador: Preliminary study. Applied Clay Science, 101, 619-622.

Kadir, A. A. & Mohajerani, A. (2015). Effect of heating rate on gas emissions and properties of fired clay bricks and fired clay bricks incorporated with cigarette butts. Applied Clay Science, 105, 269-276.

Kazmi, S. M. S., Abbas, S., Saleem, M. A., Munir, M & Khitab, A. (2016). Manufacturing of sustainable clay bricks: Utilization of waste sugarcane bagasse and rice husk ashes. Construction and Building Materials, 120, 29-41.

Kizinievič, O., Kizinievič, V & Malaiškienė, J. (2018). Analysis of the effect of paper sludge on the properties, microstructure and frost resistance of clay bricks. Construction and Building Materials, 169, 689-696.

Monteiro, S. N., Alexandre, J., Margem, J. I., Sánchez, R. & Vieira, C. M. F. (2008). Incorporation of sludge waste from water treatment plant into red ceramic. Construction and Building Materials, 22, 1281-1287.

Malaysian Palm Oil Board. (2018). Oil Palm Planted Area as at December 2017 (Hectares).

MS 76. (1972) Specification for bricks and blocks of fired brickearth, clay or shale - Part 2 : Metric units. SIRIM.

Mueller, H., Maithy, S., Prajapati, S., Bhatta, A. D. & Shrestha, B. L. (2008). Green brick making manual. Vertical shaft brick kiln project clean building technologies for Nepal.

Oyeleke, R. B., Yusof, M. B., Salim, M. R. & Ahmad, K. (2011). Physico-chemical properties of palm oil fuel ash as composite sorbent in kaolin clay landfill liner system. International Journal of Renewable Energy Resources, 1, 37-44.

Pourakbar, S., Asadi, A., Huat, B. B. K. & Fasihnikoutalab, M. H. (2015). Stabilization of clayey soil using ultrafine palm oil fuel ash (Pofa) and cement. Transportation Geotechnics, 3, 24-35.

Ramachandran, V. S., Paroli, R. M., Beaudoin, J. J & Delgado, A. H. (2002). Chapter 12. Clay-based construction product. In Thermal Analysis of Construction Materials (pp. 488-530), United States of America: Noyes Publications.

Rathossi, C & Pontikes, Y. (2010). Effect of firing temperature and atmosphere on ceramics made of nw peloponnese clay sediments. part i: reaction paths, crystalline phases, microstructure and colour. Journal of the European Ceramic Society, 30, 1841-1851.

Raut, A. N. & Gomez, C. P. (2017). Development of thermally efficient fibre-based eco-friendly brick reusing locally available waste materials. Construction and Building Materials, 133, 275-284.

Sicakova, A., Draganovska, M & Kovac, M. (2017). Water absorption coefficient as a performance characteristic of building mixes containing fine particles of selected recycled materials. Procedia Engineering, 180, 1256-1265.

Silva, R. V., De Brito, J., Lye, C. Q & Dhir, R. K. (2017). The role of glass waste in the production of ceramic-based products and other applications. A review. Journal of Cleaner Production, 167, 346-364.

Šveda, M. (2007). Mathematical correlations between properties of brick at various equilibrium humidity content (Part 2). *Materials Science*, 13, 52-56.

Ukwatta, A., Mohajerani, A., Eshtiaghi, N. & Setunge, S. (2016). Variation in physical and mechanical properties of fired-clay bricks incorporating ETP biosolids. Journal of Cleaner Production, 119, 76-85.

Ul Islam, M. M., Mo, K. H., Alengaram, O. J. & Jumaat, M. Z. (2015). Mechanical and fresh properties of sustainable oil palm shell lightweight concrete incorporating palm oil fuel ash. Journal of Cleaner Production, 115, 307-314.

Wilson, M. A., Carter, M. A. & Hoff, W. D. (1999). British Standard and RILEM water absorption tests: A critical evaluation. Material Structure, 32, 571-578.

Zarina, Y., Mustafa Al Bakri, A. M., Kamarudin, H., Nizar, I. K. & Rafiza, A. R. (2013). Review on the various ash from palm oil waste as geopolymer material. Reviews on Advanced Materials Science, 34, 37-43.