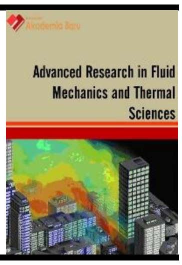
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Influence of Palm Oil Fuel Ash (POFA) towards Fire Resistance Performance of Brick

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ARTICLE INFO

Article history:
Received 1 May 2019
Received in revised form 23 September 2019
Accepted 18 October 2019
Available online 28 December 2019

Keywords:
Compressive strength; fire resistance; palm oil fuel ash; water absorption test.

ABSTRACT

Material waste is one of the major problems in Malaysia. Factors such as large population growth, urbanization and rapid economic growth had contributed to the increasing of waste generation. In recent years, awareness and concern over the impact of the increase in the amount of waste in landfills has made many members of the science and technology especially in the field of engineering to adapt the waste into valuable products. Palm oil fuel ash (POFA) is a by-product from biomass thermal power plants where oil palm residues are burned to generate electricity. Since palm oil is one of the major raw materials used to produce bio-diesel, it is likely that the production of POFA will increase every year. Rapid generation of POFA causes increase in the landfill areas. Besides, the waste did not give any profit to industries because it could not be used as fertilizer. According to previous studies, it has proven that POFA is one of the agriculture waste that high potential as cement replacement because POFA is known as pozzolanic materials [1-3]. Therefore, due to these Malaysian researchers have done numerous of studies on the potential of POFA as the replacement of cement in the construction materials since POFA can act as the pozzolanic materials. In addition, the usage of POFA could reduce the emission of carbon dioxide (CO_2) produced by cement in concrete. Thus, this study is focusing on the usage of POFA as replacement material in the production of concrete brick. Among brick properties that have been identified in this study are density, compressive strength, water absorption and fire resistance. The percentage of POFA used as cement replacement are 0%, 10%, 15%, 20% and 25%. From this study, it was found that, the replacement of POFA in the brick production gave significant impact towards brick properties

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1. Introduction

Developing countries like Malaysia are undergoing significant infrastructural change and increasing demand for masonry blocks or bricks. Bricks in Malaysia can be manufactured with the combination of perfect proportion of sand, cement, and water. It has many variations of sizes, type, materials used, classes, and usage depending to the region, period and climate of proposed construction. However, high demand in construction materials such as concrete brick has increased the emission of carbon dioxide (CO_2) to the environment. The emission of CO_2 was released by the chemical reaction of cement in the concrete. Cement is the major construction material that being used in the production of concrete and mortar in construction industries. Large usages of cement not only diminish the natural resources yet contribute to the high emission of carbon dioxide and other greenhouse gas (GHGs) [4]. Based on research and scientific reports it has been proved that, one of the main factor of global warming is due to the high concentration of carbon emission in the atmosphere [5]. Regarding to United Nation Environment Programme, UNEP (2009) one-third of carbon emission contributed by the building sector annually. Other scientific report stated that, 7% of the world's carbon dioxide emission was produced by the cement production in industries [6]. As well as the development of construction industry, Malaysia is also well known for its major agro-industry that has significant impact in national economy. One of its largest contributors is palm oil plantation. Palm oil is popular vegetable oil for cooking and food processing and Malaysia is also known of one of the largest producer of palm oil in the world. Palm oil fuel ash or POFA is a by-product produced after combustion in palm oil mill and generally about 5% palm oil fuel ash by weight of solid wastes is produced [7].

Major reason for this study is to help conserve the environment and build an environmental-friendly space for future generations. Considering the amount of POFA arising from palm oil mills in Malaysia and the desire to address environmental problem posed by this waste, there is a need to examine further on the application and usage of POFA at higher volume especially in masonry manufacturing. Therefore, this study was identified the density, water absorption, compressive strength and fire resistance performance of bricks containing POFA for sustainable construction as well as to put POFA into economic benefit. The study conducted also observed the effect of palm oil fuel ash that was used to replace cement in bricks by proportions of 0%, 10%, 15%, 20% and 25% by mass.

2. Experimental Program

2.1 Materials

In this study, raw materials that have been used for the production of brick are Ordinary Portland Cement (OPC), river sand, POFA, tap water and super plasticizer.

2.1.1 Ordinary Portland Cement (OPC)

The classification of OPC used in this study is type 1 based on the ASTM C150 [8]. The supplier for this cement is Tasek Corporation Berhad which certified by SIRIM. Cement used was kept in an air tight container to prevent any moisture contact. The chemical composition of OPC used in this study has shown in Table 1.

Table 1
Chemical composition of OPC and POFA

Chemical Composition	OPC	POFA
Silicon Dioxide (SiO_2)	14.6	55.20
Aluminium Oxide (Al_2O_3)	3.95	4.48
Ferric Oxide (Fe_2O_3)	3.46	5.44
Calcium Oxide (CaO)	57.1	4.12
Potassium Oxide (K_2O)	0.51	2.28
Magnesium Oxide (MgO)	1.62	2.25
Sodium Oxide (Na_2O)	-	0.1
Sulfur Trioxide (SO_3)	3.43	2.25

2.1.2 Palm oil fuel ash (POFA)

The POFA used in this study has been obtained from palm oil factory located at Pekan Nanas, Pontian, Johor. Laboratory investigations, based on short and long-term study have shown that this ash has not only enabled the replacement of Ordinary Portland Cement but also found to play an effective role in producing strong and durable concrete. The percentage variations of POFA tested and used in this study were 0%, 10%, 15%, 20% and 25%. To prepare POFA for this research, firstly POFA was collected from palm oil factory. Next, the POFA was oven-dried for 24 hours at 105^{o}C±5. To ensure the consistency of size, POFA was sieved using sieve plate with the size of 300µm according to BS 410 [9]. Table 1 shows the chemical composition of POFA obtained from the XRF analysis.

2.1.3 Fine aggregate

In the bricks production, river sand has been used as fine aggregates. River sand, same as POFA, was sieved by sieve plate to ensure that it does not consist any impurities and in order to have a consistent size. But before that, they had gone through the process of oven dry for at least 24 hours at the temperature of 105^{o}C±5. In this research, the sieve analysis of sand was performance in accordance to ASTM C 136 [10].

2.2 Mix Proportion

The proportion of material needed to be properly selected to meet the specification required. The requirement for brick mix include requirement on strength, water absorption and fire resistance. As for cement replacement, POFA was substituted at percentage by weight of 0%, 10%, 15%, 20% and 25%. All bricks were cured for 7 days and 28 days. Total specimens that have been prepared were 60 bricks with size of 215 mm × 102.5 mm × 65 mm. 30 samples were used for density test and next were used for compressive strength test. 15 samples were used for water absorption test. Meanwhile, the remaining of 15 samples was used for fire resistance test. Table 2 shows the mix proportion of brick mix.

Table 2

Mix proportion of brick mix

Mix	Mix Proportion Cement (kg)	POFA (kg)	Sand (kg)	w/c ratio (kg)	Super-plasticizer (ml)	POFA percentage (%)
1	0.71	0.00	2.14	0.36	8	0
2	0.64	0.07	2.14	0.36	8	10
3	0.60	0.11	2.14	0.36	8	15
4	0.57	0.14	2.14	0.36	8	20
5	0.53	0.18	2.14	0.36	8	25

2.2.1 Curing process

After casting process, the bricks were left inside the laboratory for at least 24 hours. After that, the brick were removed from the mould and undergoes curing process for 7 and 28 days. In this research, the method of curing used is air curing. The bricks were left inside the laboratory with room temperature until the day of test.

3. Test Method

3.1 Hardened Density Test

In this study the hardened brick test was conducted accordance to BS EN 12390-7 [11] in which determination of the brick mass will be as-received condition. The measurement of brick density was conducted at the age of 7 and 28 days. Three samples have been prepared for every mix proportion.

3.2 Compressive Strength Test

Compressive strength test for this study was conducted according to the ASTM C140-11a [12]. For this test, three brick samples have been prepared for every mix proportion and all the samples tested are full-sized. Any excess moisture or any particles must be removed from the brick surface and the loading plate of the machine before conducting the test. All the brick samples were cured by air curing process in the laboratory until the day of test. For this test, the samples were also tested at the age of 7 and 28 days. Figure 1 shows hydraulic compression machine used for compressive strength test.

Fig. 1. Hydraulic compression machine

3.3 Water Absorption Test

Water absorption test was conducted in order to determine the percentage of the water absorption by the brick. The test was accordance to the BS 1881: 122 [13]. Initially, the brick samples were dried in the oven at 100°C ± 5°C for 24hours. The samples were then left to cool down before been immersed in the water tank for another 24hours as shown in Figure 2. The weights of samples were taken before and after the samples were immersed in the tank in order to determine the percentage of the water absorption. This test was conducted at the age of 7 and 28 days.

Fig. 2. Water absorption test

3.4 Fire Resistance Test

In this study, fire resistance test was conducted in order to determine the compressive strength of bricks after been exposed to elevated temperature. The test was conducted by using electric furnace. The range of temperature used in this test was 25°C, 300°C and 500°C. The heating rate for this test is 10°C/min and the test was conducted for two hours. After the test, the bricks were left in the furnace for 24 hours to ensure the bricks totally cooled before it was tested. Figure 3 shows the electric furnace used for fire resistance test.

Fig. 3. Electric furnace for fire resistance test

4. Results and Discussion

4.1 Density Test

Figure 4 shows the density of bricks with various percentage of POFA at the age of 7 and 28 days. As can be seen, generally the brick density was decreased as the replacement percentage of POFA increase. For example, brick sample with 0% POFA (control brick) recorded the highest density which are 2150 kg/m^3 for 7 days as compared to brick with 10%, 15%, 20% and 25% where the brick density were 2064.29 kg/m^3, 1978.57 kg/m^3, 1892.86 kg/m^3 and 1864.29 kg/m^3 respectively. This shows that, the replacement of cement by POFA has slightly affected the brick density. This was due to the increment of the formation of pores in the brick containing POFA. The formation of pores in the brick was due to the POFA structure which coarser than cement. Similar finding was found by Rahman *et al.,* [6] where in their study, the replacement of cement by POFA has contributed in the reduction of density due to the coarser structure of POFA.

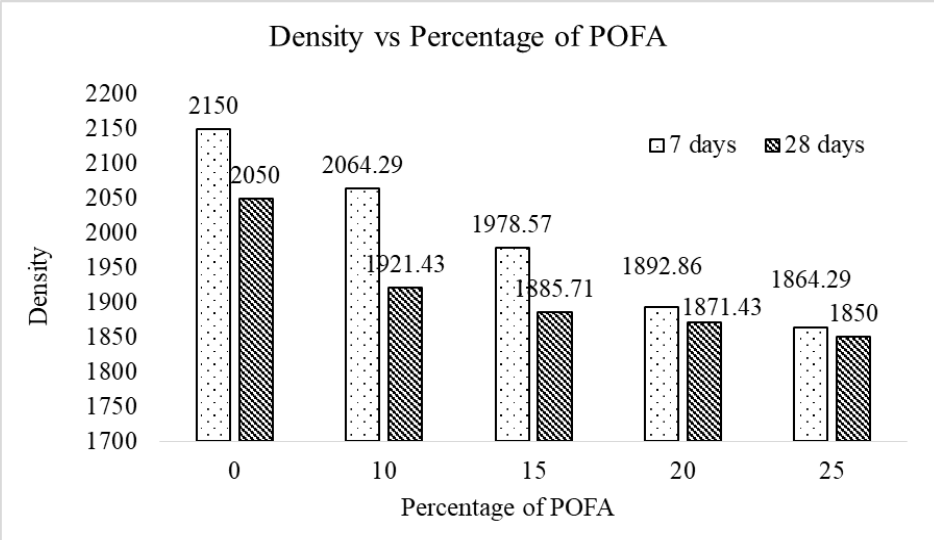

Fig. 4. Density of brick vs various percentage of POFA in brick at the age of 7 and 28 days

Meanwhile, it was found that brick age also affected the density of the brick. It can be seen that, the brick density at the age of 28 days were lower as compared to the brick at 7 days. From the figures, the decrement in the brick density at 28 days was about 1% to 7%. This might due to the loss of water content in the brick throughout the air curing process.

4.2 Compressive Strength Test

The compressive strength of bricks with various percentage of POFA for 7 and 28 days are as shown in Figure 5. Generally, based on the figure, compressive strength of bricks were decreased as the percentage of POFA increase. For instance, the strength of normal brick at age 28 is 27.4 MPa. However, the replacement of 10% of POFA has reduced the brick strength up to 23.4% as compared to normal brick. As can be seen in the figure, the brick strength result were decline where brick with 15%, 20% and 25% of POFA continuously decreased the brick strength about 43.8%, 55.5% and 66.1% respectively. Although the brick strengths were decreased as the percentage of POFA increased, the brick strengths are still acceptable according to requirement stated in ASTM C129-11 [14] where for non-load bearing brick, the minimum requirement of brick strength is 3.45 MPa for every single unit.

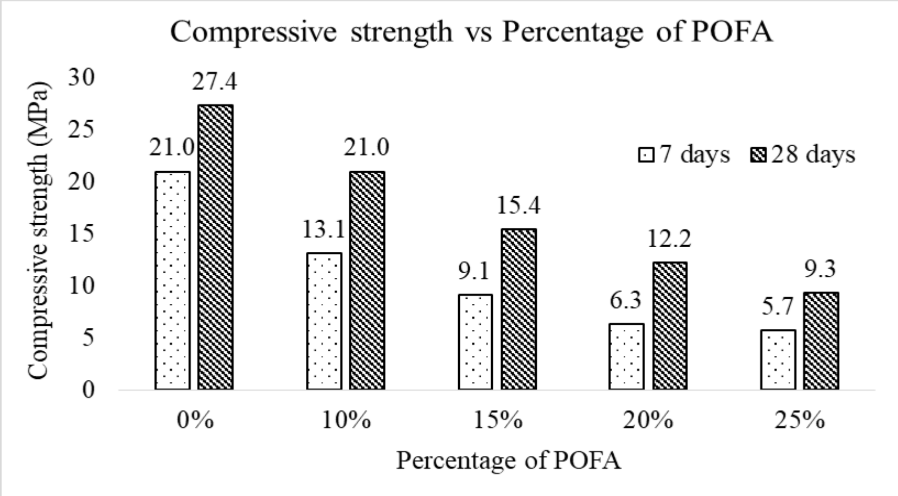

Fig. 5. Compressive strength of bricks with various percentage of POFA at the age of 7 and 28 days

Other than percentage of material replacement, brick ages also give impact towards brick strength. Based on Figure 2, strength of the brick were higher at 28 days as compared to 7 days. The increase in strength at later age might due to the hydration process taken by cement and POFA in the brick mixture. However, it was observed that, the existence of POFA impacted the percentage of increment of brick strength. This can be seen that, the percentage of increment of strength for normal brick was only 29% as compared to brick strength at 7 days. Meanwhile, for brick containing POFA, the percentage of strength increment was 60% up to 93% as compared to 7days brick strength. This shows that, POFA could increase the brick strength higher and faster as compared to the brick without POFA.

4.3 Water Absorption Test

Figure 6 shows the percentage of water absorption with various percentage of POFA at 28 days. From the graph it shows that the increment of POFA in the mixture of brick caused increment in percentage of water absorption. Controlled sample with 0% of POFA has the lowest percentage of water absorption while the highest percentage was the brick that contains 25% of POFA which is 13.4%. A slight increase percentage of water absorption can be seen from 10%, 15% and 20% with the difference of range 0.06 to 0.07%. It can be concluded that the higher the percentage of POFA, the higher the water absorption percentage of bricks. The increment of percentage of water absorption was due to the characteristic of POFA which was coarser in structure and highly absorbent material. The same observation was found by Rahman *et al.,* [6] where they have made a comparison on water absorption of POFA concrete and normal concrete. From the findings, it shows that, the existence of POFA in the concrete has slightly contributed to the increment of water absorption of the concrete. They have concluded that, increase in percentage of water absorption was due to the greater porosity of POFA which tend to favour water absorption.

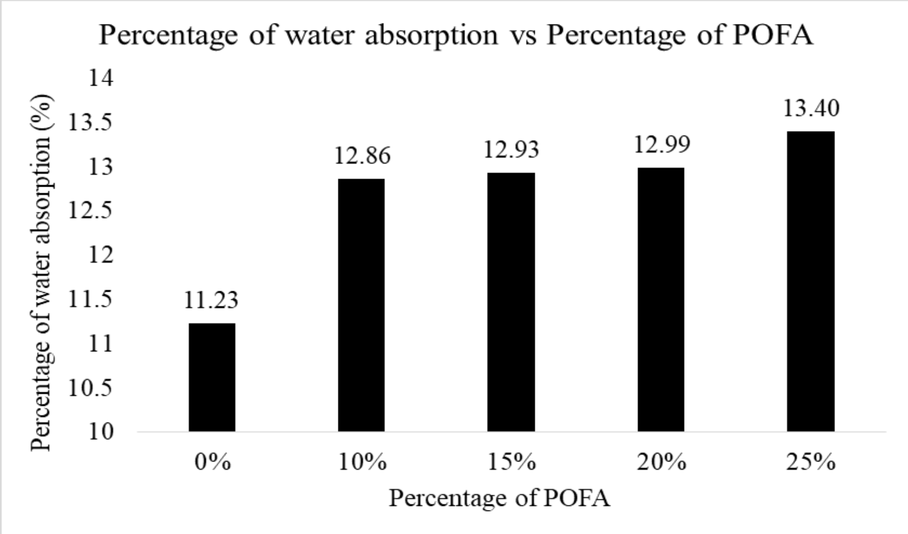

Fig. 6. Percentage of water absorption with different percentage of POFA

4.4 Fire Resistance Test

Fire resistance test was conducted to determine the compressive strength of bricks after been exposed to high temperature for two hours with heating rate of 10°C/min. The temperature used for this test was 25°C, 300°C and 500°C. After two hours of test, the bricks were left inside the electric furnace for 24 hours before they were tested for compressive strength. Figure 7 shows the compressive strength of the bricks with different percentage of POFA at room temperature and after been tested with fire resistance test at elevated temperature of 300°C and 500°C.

Figure 7 shows the compressive strength of bricks after been exposed to three different temperature of testing. Based on the figure, it can be seen that, compressive strength of bricks were decreased as the temperature increased. For example, brick strength of 10% POFA was 20.5 MPa at 25°C, while the strength was dropped to 15 MPa and 12.3 MPa at temperature 300°C and 500°C respectively. Meanwhile, for brick with 15%, 20% and 25% of POFA, there were slight drops in strength when bricks were exposed to elevated temperature. However, significant reduction in strength of was observed for brick without POFA (normal brick). The strength of normal brick at room temperature was 27.4 MPa but the strength was decreased up to 53% to 56% when been exposed to temperature of 300°C and 500°C respectively. This shows that, the existing of POFA in bricks has slowed down the reduction in strength of brick when exposed to high temperature.

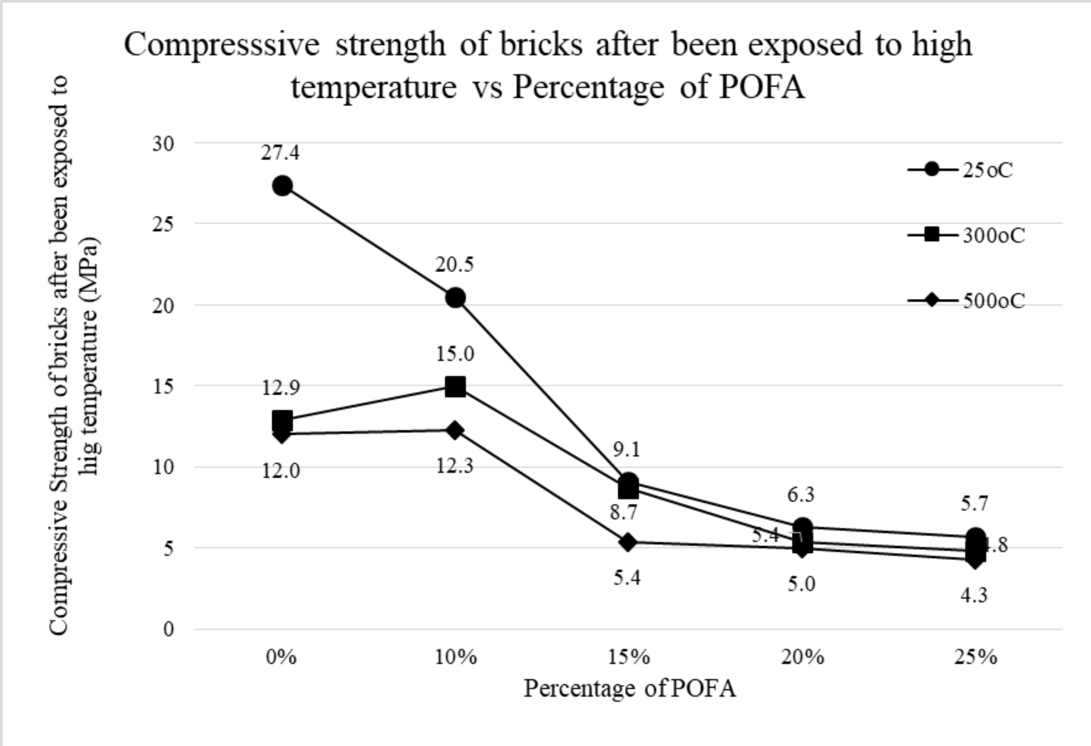

Fig. 7. The compressive strength test after been exposed to high temperature with different percentage of POFA at the age of 7 and 28 days

Generally, according to the result, it can be concluded that high temperature exerted on bricks affected its compressive strength which resulting the bricks to have low strength. After fire resistance test, the lowest compressive strength of each type of bricks was observed at temperature of 500°C. However, it was found that compressive strength of all bricks were above the minimum requirement of non-load bearing brick stated in ASTM C129-11 [14] where the required strength is 3.45MPa for individual unit.

5. Conclusion

Based on this study it can be conclude that the density of bricks was slightly affected by the existing of POFA. As the percentage of POFA increase, the density of brick decreased. It can be seen that, the replacement of cement by POFA has decreased the brick density from 6% to 10% as compared to normal brick. The reduction in density was due to the high formation of porosity in the brick. Formation of porosity was due to the coarser structure of POFA as compared to the cement structure.

Similarly to density, it was observed that compressive strength of brick was decreased as the percentage of POFA increased. However according to the findings, it shows that all the bricks produced complied with ASTM C129 [14] requirement which the minimum net area compressive strength for non-load bearing brick are 3.45 MPa for individual unit. Based on this study, the lowest compressive strength was brick with 25% POFA with value of 9.3 MPa. This shows that, the replacement of POFA did not compromise the performance of brick in term of strength.

Meanwhile, water absorption test shows that the higher percentage of POFA as cement replacement in bricks, the higher ability of bricks to absorb water. The result shows that the controlled sample has the lowest percentage of water absorption while the bricks with the highest percentage of POFA with 25% has the highest percentage of water absorption. It can be conclude that, increase in percentage of water absorption was due to the greater porosity of POFA which tend to favour water absorption.

For fire resistance test, it shows that the various percentage of POFA in bricks placed at room temperature gives the highest value of compressive strength. The controlled samples have higher compressive strength after been exposed to high temperature compared to bricks containing POFA. Bricks with higher percentage of POFA have the lowest compressive strength when tested with temperature of 500 ^{o}C. However, it was found compressive strength for all bricks that subjected to high temperature were above the minimum strength required for non-load bearing brick [14].

Acknowledgement
The authors gratefully acknowledge the Universiti Tun Hussein Onn Malaysia and Ministry of Higher Education for providing the financial support through the Fundamental Research Grant Scheme (FRGS), Vot 1618 and Postgraduate Research Grant (GPPS), Vot U77.

References

[1] Islam, Mohammad Momeen Ul, Kim Hung Mo, U. Johnson Alengaram, and Mohd Zamin Jumaat. "Durability properties of sustainable concrete containing high volume palm oil waste materials." *Journal of Cleaner Production* 137 (2016): 167-177.
[2] Awal, ASM Abdul, and M. Warid Hussin. "Effect of palm oil fuel ash in controlling heat of hydration of concrete." *Procedia Engineering* 14 (2011): 2650-2657.
[3] Mohammadhosseini, Hossein, ASM Abdul Awal, and Abdul Rahman Mohd Sam. "Mechanical and thermal properties of prepacked aggregate concrete incorporating palm oil fuel ash." *Sādhanā* 41, no. 10 (2016): 1235-1244.
[4] Rehan, Rashid, and Moncef Nehdi. "Carbon dioxide emissions and climate change: policy implications for the cement industry." *Environmental Science & Policy* 8, no. 2 (2005): 105-114.
[5] Kibwami, Nathan, and Apollo Tutesigensi. "Enhancing sustainable construction in the building sector in Uganda." *Habitat International* 57 (2016): 64-73.
[6] Rahman, Muhammad Ekhlasur, Ang Lye Boon, Agus Setyo Muntohar, Md Nafeez Hashem Tanim, and Vikram Pakrashi. "Performance of masonry blocks incorporating palm oil fuel ash." *Journal of cleaner production* 78 (2014): 195-201.
[7] Sata, Vanchai, Chai Jaturapitakkul, and Kraiwood Kiattikomol. "Utilization of palm oil fuel ash in high-strength concrete." *Journal of Materials in Civil Engineering* 16, no. 6 (2004): 623-628.
[8] ASTM C150/C150M-11. *Standard Specification for Portland Cement*. ASTM Masonry Standard for the Building Industry 7th Edition 2012.
[9] BS 140 : *Specification for Test Sieve*. London: BS 410. 1986
[10] ASTM C136-06. *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*. ASTM Masonry Standard for the Building Industry 7th Edition 2012.
[11] BS EN 12390-7. *Testing Hardened Concrete. Density of Hardened Concrete*. British Standard 2009.
[12] ASTM C140- 11a. *Standard Test Method for Sampling and Testing Concrete Masonry Units and Related Units.* ASTM Masonry Standard for the Building Industry 7th Edition 2012.
[13] BS 1881: part 122. *Method for Determination of Water Absorption*. British Standard 1983
[14] ASTM C129 - 11. *Standard Specification for Nonloadbearing Concrete Masonry Units.* ASTM Masonry Standard for the Building Industry 7th Edition 2012.