

## Research Article

### Low Carbon Footprint Mortar from Pozzolanic Waste Material

Taha Mehmannaavaz, Salihuddin Radin Sumadi, Muhammad Aamer Rafique Bhutta,  
Mostafa Samadi and Seyed Mahdi Sajjadi

Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai 81300, Johor, Malaysia

**Abstract:** Nowadays, Portland cement clinker leads to emission of CO<sub>2</sub> into the atmosphere and therefore causes greenhouse effect. Incorporating of Palm Oil Fuel Ash (POFA) and Pulverized Fuel Ash (PFA) as partial cement replacement materials into mix of low carbon mortar decreases the amount of cement use and reduces high dependence on cements compared to ordinary mortar. The result of this research supported use of the new concept in preparing low carbon mortar for industrial constructions. Strength of low carbon mortar with POFA and PFA replacement in cement was affected and changed by replacing percent finesse, physical and chemical properties and pozzolanic activity of these wastes. Waste material replacement instead of Ordinary Portland Cement (OPC) was used in this study. This in turn was useful for promoting better quality of construction and innovative systems in construction industry, especially in Malaysia. This study was surely a step forward to achieving quality products which were affordable, durable and environmentally friendly. Disposing ash contributes to shortage of landfill space in Malaysia. Besides, hazard of ash might be another serious issue for human health. The ash disposal area also might create a new problem, which is the area's sedimentation and erosion.

**Keywords:** Cement replacement, low carbon footprint, mortar, waste materials

## INTRODUCTION

Portland cement clinker leads to emission of CO<sub>2</sub>. Each ton of Portland cement produces about 850 kg of CO<sub>2</sub> emitted into the atmosphere and therefore causes greenhouse effect. Thus, it is essential to reduce production of Portland cement clinker. To find a solution for this problem, partial replacement of Portland cement with pozzolanic materials is proposed. Mineral additives (pozzolans) such as fly ash, rice husk ash, palm oil fuel ash, etc., are used as cement replacement. These materials have been reported to increase stability of paste, mortar and concrete (Abdullah *et al.*, 2006; Awal and Hussin, 1997; Awal and Shehu, 2013; Bamaga *et al.*, 2010). Malaysia is ranked as the world's largest producer of palm oil, reporting 52% of the whole world's oils and this industry is the main agricultural industry in the country (Sumathi *et al.*, 2008). In 2006, Malaysia recorded production of approximately 15 million tons of crude palm oil (M.P.O.B., 2006). A comprehensive research has been carried on using POFA, PFA, blast furnace slag, rice husk ash, etc., as a cement replacement material in concrete (Abdul Awal, 1998; Hossain *et al.*, 2011; Khairunisa, 2009; Noor Ahmed, 2007; Sumadi, 1993). These materials can also improve durability of concrete. Levels of Portland cement replacement

containing POFA vary significantly with contents of more than 30% by weight which is common in some regions, especially in Malaysia (Abdul Awal, 1998; Hossain *et al.*, 2011; Khairunisa, 2009; Sumadi, 1993). The POFA which was used in this study had the same properties as standard ASTM C 618-05 because POFA does not have any standard specifications in Malaysia; but, ASTM C 618-05 (2005) is specified for use of Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolans in concrete. Anyway, use of by-products in building materials is controlled not only by suitability of these materials for this purpose but also by local economy and competitive position of other building materials within the area. In terms of technology, it may be possible partly to replace sand or binding material with by-products if it is accompanied by improving the end products or reducing the production cost.

This experiment aimed to explore relevance of POFA and PFA as a partial replacement of cement in low carbon-mortar. Efforts were made to partially replace cement with Palm Oil Fuel Ash (POFA) and Pulverized Fuel Ash (PFA) to produce cement. The main objective was to determine effect of incorporating different percentages of POFA-PFA and compressive strength and density of the samples after 7, 28 and 90 days, respectively. All the samples were kept in a water tank and water curing regime was investigated.

**Corresponding Author:** Taha Mehmannaavaz, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai 81300, Johor, Malaysia

This work is licensed under a Creative Commons Attribution 4.0 International License (URL: <http://creativecommons.org/licenses/by/4.0/>).

Moreover, strength development of the samples was studied in 90 days of curing.

### MATERIALS

**Cement:** Ordinary Portland Cement (OPC) of Holcim Top Standard Cement brand from Holcim Cement Manufacturing (Malaysia) SdnBhd was used in this study. The OPC used was prepared by Type I Portland Cement as in ASTM C150 (ASTM C 150-05, 2005).

**POFA:** Palm Oil Fuel Ash (POFA) used is obtained from Kahang palm oil mill in Kluang Johor, Southern state of Malaysia. The material was ground using a modified Los Angeles abrasion test machine having 8 stainless bars, each of which is 12 mm diameter and 800 mm long in order to acquire finer particles (Awal and Abubakar, 2011; Hussin and Awal, 1996).

**PFA:** Pulverize Fuel Ash (PFA) is a by-product of the combustion of pulverized coal in thermal power plants. The material was obtained at the power plant dust collection systems from the exhaust gases of fossil fuel power plants. PFA was supplied by Sultan Abdul Aziz Generation Station Kapar, located from Klang, Selangor, Malaysia. In this research, PFA, Class F which is low calcium PFA under (ASTM C 618-05, 2005), "Standard Specification for Coal Fuel Ash and Raw or Calcined Natural Pozzolon for Use in Concrete" was used.

**Sand (aggregate gradation):** The natural river sand was used during this investigation and 50% passed from

600 micron sieve, 30% passed from 1.18 mm sieve and 20% passed from 2.36 mm sieve.

**Water:** In this experiment, tap water was used for manufacturing the mortar.

**Super plasticizer:** The super plasticizer used during this study had trade name of SIKAMENT NN as chemical admixture. According to ASTM C 494/C 494 M-05 (2005), it was type F high range water reducing admixture and from group Sulphonated Naphthalene Formaldehyde condensates (SNF) in dry powder form.

Table 1 and 2 illustrated chemical combination and physical properties of OPC, POFA and PFA.

The materials have relatively spherical, irregular particles in shape; a typical electron micrograph and x-ray diffraction pattern of the ashes is shown in Fig. 1 and 2.

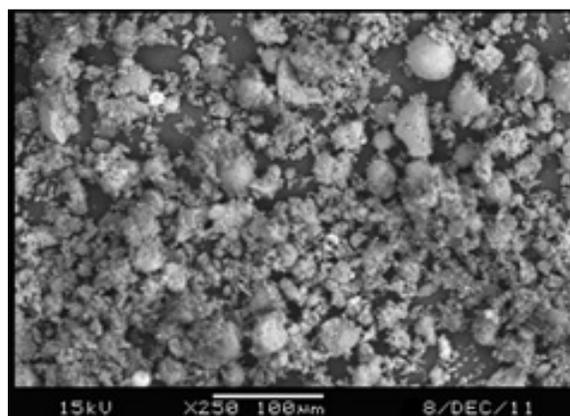
**Specimen preparation and testing:** All eleven batches including one control batch, each contained 3 cubes of

Table 1: Chemical combination of OPC, POFA and PFA

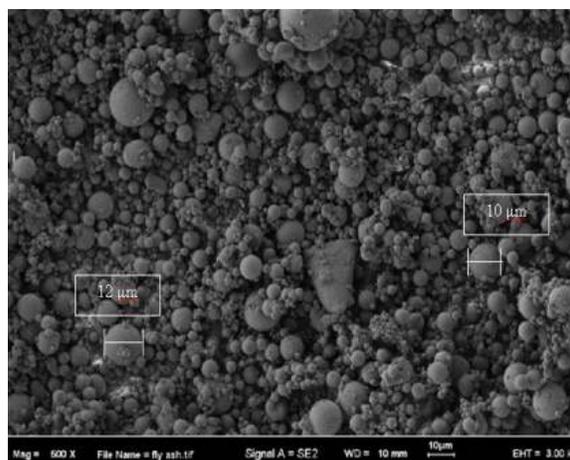
Chemical combination (%)	OPC	POFA	PFA
SiO <sub>2</sub>	16.40%	63.70%	53.60%
Al <sub>2</sub> O <sub>3</sub>	4.240%	3.68%	26.60%
Fe <sub>2</sub> O <sub>3</sub>	3.530%	6.27%	5.36%
CaO	68.300%	5.97%	7.28%
K <sub>2</sub> O	0.220%	9.15%	1.30%
P <sub>2</sub> O <sub>5</sub>	-	4.26%	1.51%
MgO	2.390%	4.11%	0.67%
CO <sub>2</sub>	0.100%	0.10%	0.10%
SO <sub>3</sub>	4.390%	1.59%	0.63%
Cl	-	0.50%	-
TiO <sub>2</sub>	-	0.30%	1.94%
Mn	-	0<LLD	0<LLD
Na	-	0<LLD	-
Mno	0.150%	-	-
Ti	0<LLD	-	-
SrO	-	-	0.33%
BaO	-	-	0.20%
Zr	-	-	0<LLD

Table 2: Physical properties of OPC, POFA and PFA

Physical properties	OPC	POFA	PFA
Specific gravity	3.15	2.42	2.62
Particle retained on 45 µm sieve	4.58	4.98	6.92
Median particle d10	-	1.69	-
Median particle d50	-	14.58	-
Blaine fineness (cm <sup>3</sup> /g)	3999	4935	3205
Soundness (mm)	1.00	2.00	-
Strength activity index (%)			
At 7 days	-	80	84
At 28 days	-	84	92



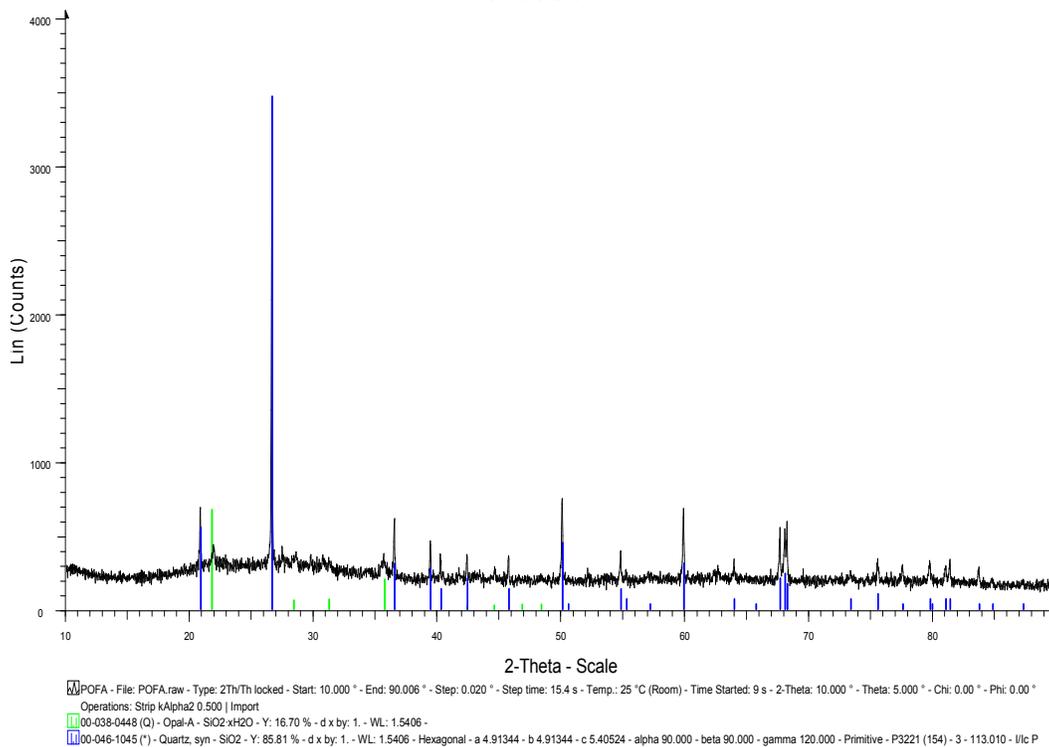
(a)



(b)

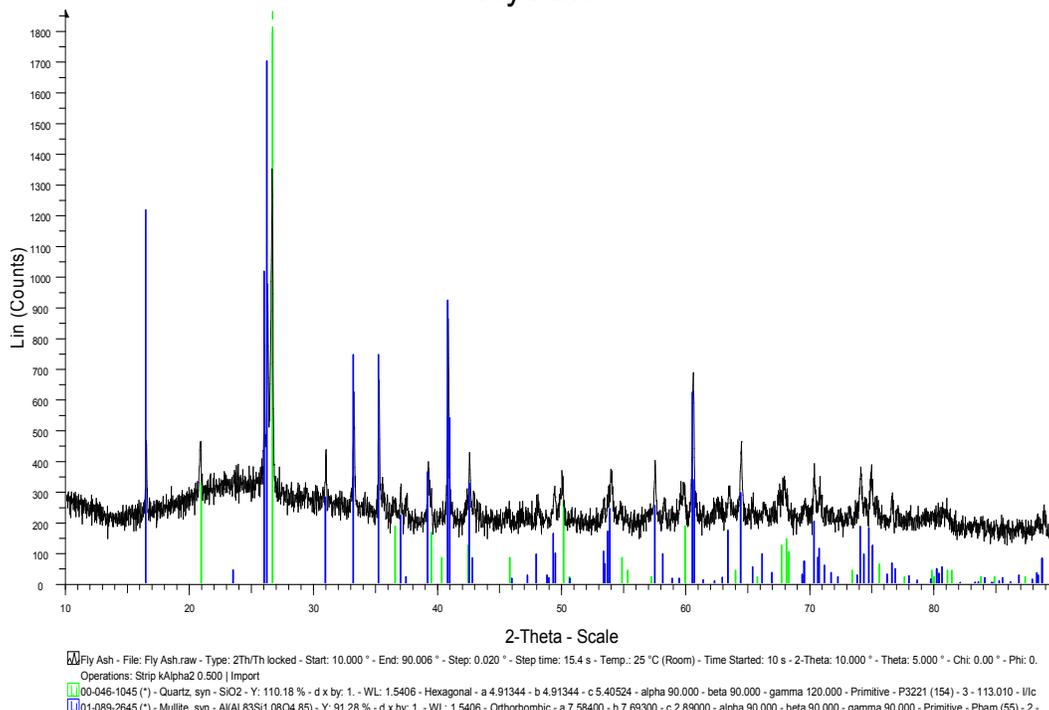
Fig. 1: Scanning electron micrograph of POFA and PFA

### POFA



(a)

### Fly Ash



(b)

Fig. 2: X-ray diffraction pattern POFA and PFA

Table 3: Detail of the mix proportion

No.	Number of batch	Mix proportion	Cement (%)	POFA (%)	PFA (%)
1	Control sample	1: 2.5	100	0	0
2	30% POFA+5% PFA	1: 2.5	65	30	5
3	30% POFA+10% PFA	1: 2.5	60	30	10
4	30% POFA+15% PFA	1: 2.5	55	30	15
5	30% POFA+20% PFA	1: 2.5	50	30	20
6	30% POFA+25% PFA	1: 2.5	45	30	25
7	30% POFA+30% PFA	1: 2.5	40	30	30
8	30% POFA+35% PFA	1: 2.5	35	30	35
9	30% POFA+40% PFA	1: 2.5	30	30	40
10	30% POFA+45% PFA	1: 2.5	25	30	45
11	30% POFA+50% PFA	1: 2.5	20	30	50

standard size 100×100×100 mm which was cast and tested. Mix ratio 1: 2.5 (binder: sand) was considered the basic mix proportion. Overall, cement replacement was adopted for all the mixes. The cement replacement was adjusted between POFA and PFA by varying their proportions accordingly. Control specimen without cement replacement was also cast to compare the values. Details of batches and mix proportion are given in Table 3. Based on the trial and error method mix series, value of water/dry mix ratio was fixed at 0.45 while dosage of the super plasticizer was fixed at 0.4% by weight of the binder. All the weighed constituents were mixed in a mixer for about 8 min to achieve uniform mix and then poured in the specimen to fill the specimen. After 24 h, the specimens were demoulded, placed in water tank for 7, 28 and 90 days, respectively and applied for water curing regime.

The specimens were removed from the curing regime 5 h before the testing. Before applying test of compressive strength, all the specimens were weighed to determine density of them. The compression testing were done by the MATEST Hydraulic test with capacity of 3000 KN. The testing machine available in Materials and Structures Laboratory, UTM, Malaysia, was used to conduct test of compressive strength for the specimens according to ASTM C109/C109M-12 (2012). For each test a set of 3 specimens was tested and the average of three was calculated nearest to the two digits after decimal.

## RESULTS AND DISCUSSION

From the Table 1 and 2 it can be seen that the materials contain high silica oxide. Influences pozzolanic reaction when it reacts with free lime thus creating extra C-S-H gels, which is beneficial to strength development of pozzolanic concrete. The sum of silica, aluminium and iron oxide of POFA and PFA is greater than 75% of the total chemical composition, that make this pozzolanic material to be classified between class C and F pozzolan (ASTM C 618-05, 2005). However the material contains low CaO in the range of 4-8% and low SO<sub>2</sub> within the minimum allowable by the standard.

Table 4 summarizes results of compressive strength of the specimens tested at different percentages of waste materials (Fig. 3 and 4). Regarding compressive strength, it can be observed from the table that compressive strength increased with partial replacement of cement with POFA and PFA. The maximum compressive strength was achieved when 30% of POFA and 10% of PFA were used as cement replacement in this sample and the achieved compressive strength was 41.02 MPa whereas compressive strength was optimum when POFA was 30% and PFA was 20%. The compressive strength was achieved 38.03 MPa when cement was partially replaced with combination of POFA and PFA (30 and 20%). Further increase in PFA content decreased

Table 4: Compressive strength (MPa)

Cement replacement	7 days	28 days	90 days
0%	27.07	36.42	36.84
30% POFA+5% PFA	20.10	36.35	38.16
30% POFA+10% PFA	15.87	31.80	41.02
30% POFA+15% PFA	14.49	27.62	33.55
30% POFA+20% PFA	12.23	30.28	38.03
30% POFA+25% PFA	13.70	22.53	35.28
30% POFA+30% PFA	10.53	21.09	31.74
30% POFA+35% PFA	11.60	21.35	28.37
30% POFA+40% PFA	11.78	20.63	32.28
30% POFA+45% PFA	10.57	19.40	31.37
30% POFA+50% PFA	10.20	18.65	27.89

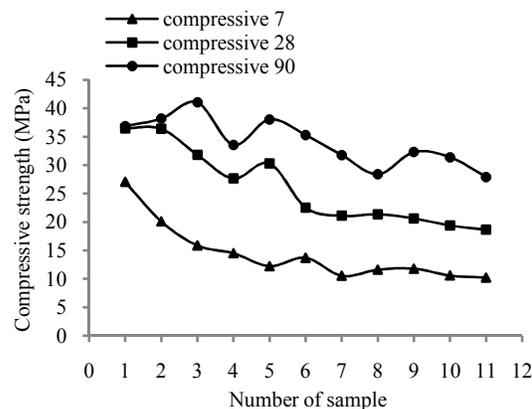


Fig. 3: Relationship between compressive strength and percentage of waste materials

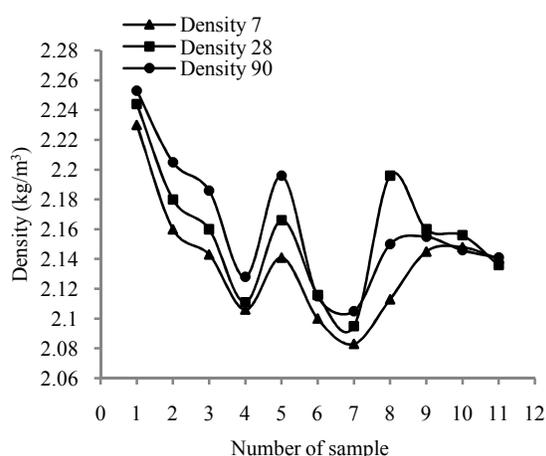


Fig. 4: Relationship between density and percentage of waste materials

Table 5: Density (kg/m<sup>3</sup>)

Cement replacement	7 days	28 days	90 days
0%	2.230	2.244	2.253
30% POFA+5% PFA	2.160	2.180	2.205
30% POFA+10% PFA	2.143	2.160	2.186
30% POFA+15% PFA	2.106	2.111	2.128
30% POFA+20% PFA	2.141	2.166	2.196
30% POFA+25% PFA	2.100	2.116	2.115
30% POFA+30% PFA	2.083	2.095	2.105
30% POFA+35% PFA	2.113	2.196	2.150
30% POFA+40% PFA	2.145	2.160	2.155
30% POFA+45% PFA	2.148	2.156	2.146
30% POFA+50% PFA	2.140	2.136	2.141

compressive strength. However, cement replacement with POFA up to 30% could be considered the most appropriate in terms of compressive strength.

Compressive strength of the specimens cured in water exhibited better performance because the water cured specimens had enough water to continue hydration process thus producing more C-S-H gel which could lead to higher strength. Hence, it can be deduced that water curing of normal concrete increased compressive strength.

The lowest density was achieved in the case of POFA 30% and PFA 30% cement replacement. It is also apparent from the Table 5 that the specimens cured in the water showed more density because they became saturated and caused production of more C-S-H gel which also contributed to increased density.

### CONCLUSION

**According to this experiment, it can be concluded that:** May achieved a low carbon mortar and reduces carbon dioxide emission by using waste material in ingredient of low carbon mortar. Improvement in compressive strength of waste material mortar was achieved by incorporating POFA and PFA as cement replacement. Optimum compressive strength of low

carbon mortar was achieved using 30% POFA and 20% PFA as partite cement replacement. Density of all mix proportions remained below that of the control sample. In addition applying waste as ingredient of low carbon mortar or concrete may decrease cost of structure.

### ACKNOWLEDGMENT

The authors wish to acknowledge the help and cooperation received from the Prof. Dr. Ir. Mohd Warid Hussin and technical staff of the Structure and Materials laboratory of the University Teknologi Malaysia (UTM) in conducting the experimental work.

### REFERENCES

- Abdul Awal, A., 1998. A study of strength and durability performances of concrete containing palm oil fuel ash. Ph.D. Thesis, Department of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.
- Abdullah, K., M.W. Hussin, F. Zakaria, R. Muhamad and Z. Abdul Hamid, 2006. POFA: A potential partial cement replacement material in aerated concrete. Proceedings of the 6th Asia-Pacific Structural Engineering and Construction Conference (APSEC 2006). Kuala Lumpur, Malaysia.
- ASTM C109/C109M-12, 2012. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens). ASTM International, Philadelphia.
- ASTM C 150-05, 2005. Standard Specification for Portland Cement. ASTM International, Philadelphia.
- ASTM C 494/C 494 M-05, 2005. Standard Specification for Chemical Admixtures for Concrete. ASTM International, Philadelphia.
- ASTM C 618-05, 2005. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete. ASTM International, Philadelphia.
- Awal, A. and M. Hussin, 1997. Effect of palm oil fuel ash on durability of concrete. Proceedings of the 5th International Conference on Concrete Engineering and Technology. Kuala Lumpur, Malaysia, pp: 299-306.
- Awal, A.S.M.A. and I.A. Shehu, 2013. Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. Fuel, 105: 728-731.
- Awal, A.S.M.A. and S.I. Abubakar, 2011. Properties of concrete containing high volume palm oil fuel ash: A short-term investigation. Malays. J. Civil Eng., 23(2): 164-176.
- Bamaga, S., M.A. Ismail, H.S. Lee and A.M.A. Budiea, 2010. Effect of incorporation of waste ash on the behavior of concrete and mortar. Int. J. Sust. Build. Tech. Urban Dev., 1(1): 74-79.

- Hossain, K.M.A., S. Ahmed and M. Lachemi, 2011. Lightweight concrete incorporating pumice based blended cement and aggregate: Mechanical and durability characteristics. *Constr. Build. Mater.*, 25(3): 1186-1195.
- Hussin, M.W. and A. Awal, 1996. Influence of palm oil fuel ash on strength and durability of concrete. *Proceedings of the 7th International Conference on Durability of Building Materials and Component*. Stockholm, pp: 291-298.
- Khairunisa, M., 2009. Properties of palm oil fuel ash cement based aerated concrete. Ph.D. Thesis, Department of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.
- M.P.O.B., 2006. Overview of the Malaysian Palm Oil Board Industry 2005.
- Noor Ahmed, M., 2007. Characteristics of ferrocement encased aerated concrete sandwich wall elements. Ph.D. Thesis, Department of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.
- Sumadi, S.R., 1993. Relationships between engineering properties and microstructural characteristics of mortar containing agricultural ash. Ph.D. Thesis, Department of Civil Engineering, Universiti Teknologi Malaysia, Malaysia.
- Sumathi, S., S. Chai and A. Mohamed, 2008. Utilization of oil palm as a source of renewable energy in Malaysia. *Renew. Sust. Energ. Rev.*, 12(9): 2404-2421.