Characteristics of Concrete Using Oil Palm Shell as Lightweight Aggregate and Ashment as Binder

Usman Aliyu **Jalam**[1], Abdulrahman Aliyu **Jalam**[2] and Dauda **Ali**[3]

[1]Department of Architecture, Abubakar Tafawa Balewa University, Bauchi - Nigeria, [2]Department of Quantity Surveying, Abubakar Tafawa Balewa University, Bauchi - Nigeria, [3]Department of Architecture, Federal Polytechnic, Bauchi – Nigeria

ABSTRACT

Concrete has been identified as one of the most common building material with high embodied energy. Investigations on lightweight concrete using oil palm shell (OPS) as coarse aggregate were attempts to find an alternative material to the use of crushed granite in concrete with a view to reducing environmental pollution resulting from the accumulation of OPS as waste from palm oil mills. This paper investigated some important characteristics of concrete made with OPS as coarse aggregate and rice husk ash (RHA) partially replacing Ordinary Portland Cement (Ashment) as binding agent. The compressive strength of the Ashment:OPS concrete at 28 days was found to be 62% higher than the minimum required strength of 17N/mm^2 and 22% lighter, for structural lightweight concrete recommended by ASTM C330. Ashment:OPS concrete can therefore be used in lightweight structures. The use of this concrete will reduce environmental pollution. This is because the major constituents of the concrete; OPS and RHA, are from waste.

Key Words: Lightweight Concrete, Oil Palm Shell, Ashment, Low-cost and Pollution.

1.0 Introduction

Nigeria is one of the richest countries in agricultural resources in Africa. Agriculture, particularly farming accounts for about 37% of Nigeria's GDP and engages about 43% of the economically active population (Food and Agriculture Organisation, 2013). Rice and oil palm are amongst the major food and cash crops grown. Indeed Nigeria, with an average annual production of about 930.00 x 10^{3}MT of palm oil, competing with Colombia, is about the fourth oil palm growing country in the world after Indonesia, Malaysia, and Thailand (World Index, 2014). On another hand, an average of 3, 772.75 x 10^{3}MT of rice is produced in Nigeria annually (Federal Ministry of Agriculture, 2014). This has been sustaining several rice processing factories across the country. Subsequently, rice husk and oil palm shell as agricultural wastes from agro-industrial processing of rice and palm oil, are being generated in millions of metric tonnes (Jalam, Sumaila and Mohammed, 2014).

At oil palm mills, when the fresh fruit bunches (FFB) are processed and oil extraction takes place, solid and liquid wastes are generated. These wastes comprise of empty fruit bunches, fibre, shell, and effluent. Teo, Mannan and Kurian (2006) reported that the shell is the most disturbing of all the constituent of these wastes. This was later discovered to be disturbing because the shell does not compost due to the presence of fibrous materials (Oviasogie, Odeewale, Aisueni, Eguageni, Brown and Oko-Oboh, 2013). Teo *et al* (2006) reported that except for the *psifera* species of palm oil (which has virtually no shell to the kernel); the shell of oil palm comprises approximately 10% to 50% of the total composition of the oil palm fruitlets. By implication, between 93.00 x 10^{3}MT and 465.00 x 10^{3}MT of oil palm shell (OPS) is produced annually in Nigeria as waste.

Similarly, according to Rukzon and Chindaprasirt (2008); Olivier (2008), Oyetola and Abdullahi (2009), Allen (2010), and Oliveira *et al* (2012), about 20 - 23% of the dry mass of harvested rice paddy is husk. This implies also that between 754.55 x 10^{3}MT and 830.00 x 10^{3}MT of rice husk (RH) is also produced annually in Nigeria as waste. Although OPS and RH have gained popularity as fuel wood for domestic cooking in villages where these crops are grown and processed locally due to the prevailing energy crisis, these same wastes from large industrial processing which come in thousands of tonnes, pose a very great deal of environmental concern in terms of pollution Teo *et al* (2006) and Jalam *et al* (2014).

The growing concern for global pollution coupled with the increasing demand for low cost housing particularly in the developing countries and the concern for resource depletion has challenged researchers to seek and develop new materials relying on renewable resources. These include the use of by-products and waste materials in building construction. Teo *et al* (2006) carried out a study to investigate the performance of oil palm shell (OPS) as lightweight aggregate in structural concrete and concluded that with a compressive strength of 28.1N/mm^2 at an age of 28 days, OPS can be used as a coarse aggregate in structural concrete production and can even be used for low to moderate strength application such as structural members for low-cost houses. However, Dashan and Nwanko (2000) have earlier reported the poor performance of OPS concrete at elevated temperatures and thus recommended the use of OPS concrete only in the construction of structures where fire risk is expected to be low. The behaviour of OPS concrete in a marine environment was also previously studied by Mannan and Ganapathy, (2001). Similarly, Oyejobi *et al* (2012) reported that a compressive strength of 20.1N/mm^2 at 28 days of hydration was obtained with a concrete mix of 1:1.5:3 using OPS as aggregates. This also met the British Standard recommended minimum strength of 15N/mm^2 for structural lightweight concrete. These two studies confirmed earlier studies by Mannan and Ganapathy (2004) and Teo *et al* (2005). Earlier, Rahman (1987); Achuenu (2005); Oyekan and Kamiyo (2007); Oyekan and Kamiyo (2011); and Chik *et al* (2011) confirmed that rice husk ash (RHA) could be used to reduce the Ordinary Portland Cement (OPC) in concrete and sandcrete block mortar. In the same vein, Rukzon and Chindaprasirt (2008) discovered that palm oil ash (POA) and RHA can be used as pozzolans to replace part of Portland cement in making mortar of relatively high strength and good resistance to chloride penetration and corrosion. When RHA is mixed with cement, the hydraulic binder is termed as *ashment*. However, while Oyetola and Abdullahi (2009); and Allen (2010) reported that the optimum replacement level of OPC with RHA is 20%, Achuenu and Achuenu (2010) replaced the OPC with 30% RHA in concrete mix of 1:1:2 (OPC-RHA:Sand:Periwinkle Shell) and obtained a concrete of 8.74N/mm^2.

Achuenu and Achuenu (2010) have identified incessant increase in price of building materials including cement and aggregate as one of the major problems facing effective delivery of a large number of development projects. However, the various attempts to reduce cost of building materials and eliminate environmental pollution by investigating the characteristic performance of building materials from agricultural wastes as identified above, were fragmented and restricted to individual materials. For instance, the studies by Dashan and Nwanko (2000); Mannan and Ganapathy (2001); Teo *et al* (2006); Rukzon and Chindaprasirt (2008) and Oyejobi *et al* (2012) were all centred on OPS only using Ordinary Portland Cement (OPC) as a binder. Similarly, the studies by Rahman (1987); Bouzouba and Fournier (2001); Achuenu *et al* (2005); Oyekan and Kamiyo (2007); Oyetola and Abdullahi (2009) and Chik *et al* (2011) all focused on the performance of RHA as a pozzolana only. Although Achuenu and Achuenu (2010) studied RHA, latterite and periwinkles shells together, their study was focused on a comprehensive cost evaluation of the use of the materials using self-help/partnership rather than on the performance of the combined materials.

As such, any attempt to further reduce cost of materials particularly cement and aggregate, will aid in increasing the delivery of housing stock. This paper investigated the important characteristics of concrete made from two agricultural wastes, OPS as coarse aggregate and RHA as a partial replacement of Ordinary Portland Cement (ashment). This was aimed to produce a concrete with alternative cheap and very low embodied energy materials sourced locally, which would be used for low-cost housing construction as well as reducing environmental pollution. The structural properties investigated in this paper were compressive strength and flexural behaviour of the Ashment:OPS concrete.

2.0 Materials and Methods

The materials used in this experimental study were an *ashment* as binder obtained by replacing Ordinary Portland Cement (ASTM Type I) with 20% rice husk ash, river sand as fine aggregate, and oil palm shell (OPS) as coarse aggregate. The river sand used was obtained locally from river Dindima in Bauchi State of North Eastern Nigeria. The sand was analysed with respect to grain size, specific gravity, bulk density, fineness modulus and water absorption in accordance with ASTM C128-15 and ASTM C33. The OPS aggregates were obtained from Wamba and Lafiya towns of Nasarawa State in the North-Central part of Nigeria at local oil palm mills. The most common specie of oil palm tree found in Nigeria is *terana* as a variety of *Ealaeis guineensis.* The OPS was weathered naturally to remove oil coating on the surface of fresh OPS. It was afterward sieved and only aggregates passing through the 12.5mm sieve and retained on the 4.75mm sieve were used. The OPS was analysed as lightweight aggregate in accordance with ASTM C 618-01. 2001.

Rice husk obtained from Muda Lawal local rice mill in Bauchi was burnt in a kiln under a controlled temperature of 700^{o}C to obtain the RHA used in this study. Rukzon and Chindaprasirt (2008), Allen (2010), and Duggal (2012) have earlier reported that ash obtained by burning the below or higher than 700^{o}C is likely to be less reactive due to the presence of too much carbon or the silica contain comes in crystalline form. The Ash was later pulverised according to the Indian Standards for pozzolana: 1344. The chemical composition and physical properties of the ash were analysed.

Mass concretes of grades M10 and M15 were prepared using the above mentioned materials. Based on the properties of the fine and coarse aggregate, the mix proportions were approximated, followed by the modification of trial mixes until a concrete of good workability was achieved. For the grade M10, a mix ratio of 1:3:5 by volume batching with a free water/cement ratio of 0.55 was found to be an acceptable mix. The cement content used was found to be within the range for lightweight. No super-plasticiser was used. Mixing of concrete was carried out manually. These mix proportions were used throughout the entire study.

The grade M10 mass concrete was cast in 100mm cube moulds to produce 30 cube samples. The M15 concrete, using a mixed ratio of 1:2:3.5 and water/cement ratio 0f 0.49 was cast in a 100mm x 100mm x 400mm beam moulds. 30 beam samples were also prepared. A plastic sheet was placed on top of the moulds immediately after casting to prevent excessive evaporation from the concrete. The cast in both moulds were left for 24h (+/- 3h) in the laboratory at ambient conditions (24-28^{o}C; and relative humidity: 80% - 93%). Subsequently, all cubes and beams samples were cured in water by immersion at a temperature of 26-30^{o}C.

Compressive strength tests on three 100mm sample cubes were performed according to BS 1881: Part 4.4 (1970) at 1, 3, 7, 14, 21 and 28 days of curing, using the universal compressive testing machine in the Building laboratory of Abubakar Tafawa Balewa University, Bauchi, Nigeria. The compressive strength was determined from equation (1).

$$\text{Compressive strength} = \frac{failure\ \ load}{Area} \text{ ....(1)}$$

Flexural tests on three beams sample were also performed in accordance with BS 1881: Part 4.5 (1970) at aforementioned curing ages. The flexural strength (f_b) was determined from equation (2) when *a* (distance between the line of fracture and the nearer support) is greater than 133mm.

$$fb = \frac{Pl}{bd^2} \text{ ....(2)}$$

Or from equation (3) when *a* is less than 133mm but greater than 115mm.

$$fb = \frac{3Pa}{bd^2} \text{ ....(3)}$$

The results of both the compressive and flexural tests were recorded.

3.0 Results and Discussions

The properties of the fine aggregate and OPS are shown in Tables 1 and 2.

Table 1: Properties of the River Sand Fine Aggregate.

S/N	Properties	Value
1.	Maximum grain size	1.4mm
2.	Specific gravity	2.63
3.	Bulk density	1,620 - 1,692kg/m3
4.	Fineness modulus	4.267
5.	24-h Water absorption	3.17%

The fine aggregate is a natural sand as it was sourced from a river. The maximum grain size of 1.4mm has met the standard requirement of IS: 650 for use as fine aggregate as reported by Akers (2004) and Duggal (2012). The specific gravity of 2.63 is also within the standard requirement of between 2 - 3 as reported by Akers (2004).

Table 2: Properties of the OPS.

S/N	Properties	Value
1.	Maximum grain size	12.8mm
2.	Specific gravity	1.19
3.	Bulk density	550 - 660kg/m^3
4.	Fineness modulus	6.35
5.	Aggregate impact value	6.39%
6.	Aggregate crushing value	2.46%
7.	24-h Water absorption	28.17%

From Table 2, it can be seen that the maximum grain size of the OPS is 12.8mm. This is a little bit outside the range of between 5.12 - 12.50mm as reported by Dashan and Nwankwo (2000) and Teo *et al* (2006). This could be attributed to the fact that the OPS was sourced from different species of palm oil. Akers (2004) reported that aggregate up to 75mm could be classified as coarse aggregate. As such, the OPS used here falls within the range of coarse aggregate. The 24 hour water absorption is however slightly lower as obtained earlier by Dashan and Nwankwo (2000) and Teo *et al* (2006) when rice husk ash was not used to partially replace OPC.

Tables 3 and 4 show the physical properties and chemical composition of the RHA used. The median particle size of 10µm and specific gravity of 2.23 conforms with the earlier findings of Ruzkon and Chindaprasirt (2008).

Table 3: Physical Properties of the Rice Husk Ash.

S/N	Properties	Value
1.	Median particle size	10µm
2.	Retained on a sieve No. 325	1-3%
3.	Specific gravity	2.23
4.	Bulk density	455kg/m^3-535kg/m^3
5.	Blaine fineness	11, 200cm/g

Table 4: Chemical Composition of the Rice Husk Ash.

Constituent	Percentage Composition
Fe_2O_3	1.05
SiO_2	89.70
CaO	1.26
Al_2O_3	1.90
MgO	0.81
Lost on ignition	4.1

The total percentage composition of Iron Oxide (Fe_2O_3= 1.05%), Silicon Dioxide (SiO_2 = 89.70%), Calcium Oxide (CaO = 1.26%), Aluminium Oxide (Al_2O_3 = 1.90%) and Magnesium Oxide (MgO = 0.81) was found to be 94.72%. The Silicon Dioxide (SiO_2 = 89.70%) is very close to 87.55%, 93.2%, 91.75% and 95% as reported by Al-Khalaf & Yousif (1984), Ruzkon & Chindaprasirt (2008), Nilantha *et al* (2010), and Allen (2010) respectively, but very higher than 67.03% as obtained by Oyetola & Abdullahi (2009). The slight difference in percentage composition might have resulted from the method of preparation of the ash and the species of the rice used. The total oxides content of 94.72% however, satisfies the 70% ASTM C618 (2001) and IS: 3812 requirements as a natural pozzolana. The lost on ignition of 4.1 suggest a very near complete burning with very negligible or no carbon left not burnt.

Table 5: Properties of Ashment:OPS Concrete.

Air-dry density	1, 864.33kg/m^3
28 Days Compressive Strength	27.5N/mm^2
28 Days Flexural Strength	4.13N/mm^2

Lightweight concretes normally have densities of less than 1,920kg/m^3 (ASTM C567, 2000). As can be seen from Table 5, the density of the Ashment:OPS concrete falls within this limit, thus making it lightweight. Compared to normal concretes with about 2,400kg/m^3, Ashment:OPS concrete is approximately 22% lighter. Earlier, Teo *et al* (2006) reported that OPS concrete would decrease 20% dead load when used in construction. Although, the density of the Ashment:OPS concrete is further lighter by about 5% in comparison with the density of a OPS concrete (1,963kg/m^3) as obtained by Teo *et al* (2006), it suggests here that Ashment:OPS concrete would decrease dead load by about 22%. The possible reasons for the further decrease in density of Asment:OPS in comparison with OPS concrete as obtained by Teo *et al* (2006) could be attributed to two reasons. Firstly, the binding agent used by Teo *et al* (2006) was 100% OPC while in this work, the OPC was replaced at 20% with RHA. The RHA used in this study as reported in Table 3, has a compacted bulk density of 535kg/m^3. This is about 62% lighter than OPC. Secondly, no super-plasticiser was used in this study in comparison with Teo *et al* (2006) where super-plasticiser was added to the OPC at 1.4 l/100kg of OPC. Tables 6 and 7 show the results of the compressive strength and flexural strength development of the Ashment:OPS Concrete.

Table 6: Compressive Strength Development of Ashment:OPS Concrete.

Percentage OPC:RHA (%)	Age of curing (Days)	Average failure load (kN)	Average compressive strength (N/mm^2)
80:20	1	108.50	10.85
80:20	3	142.00	14.20
80:20	7	151.00	15.10
80:20	14	202.10	20.21
80:20	21	210.90	21.09
80:20	28	275.00	27.50

Table 7: Flexural Strength of the Ashment:OPS Concrete.

Percentage OPC:RHA (%)	Age of curing (Days)	Average Modulus of Rupture (N/mm^2)
80:20	1	1.19
80:20	3	1.70
80:20	7	1.96
80:20	14	2.83
80:20	21	3.16
80:20	28	4.13

Sample cubes tested at a curing age of 28 days produced an average strength of 27.5N/mm^2. This is about 62% higher than the minimum required strength of 17 N/mm^2 for structural lightweight concrete as recommended by ASTM C330. Although OPS is an organic material, an observation of a structure built with Asment:OPS concrete (Figure 1) over a period of 18 months did not show any biological decay. This further confirms the findings of Teo *et al* (2006) that no evident of biological decay was observed even as their studied cubes gained strength after 6 months. Similar to the observation made by Teo *et al* (2006), it was also observed that at the earlier ages of testing (3 to 28 days), the compression failure in the concrete was mainly caused by the failure in the bond between the binder paste (Ashment) and the OPS aggregate. The crack path was noticed to have gone around the OPS. At later ages however, the mortar-aggregate bond became stronger making the crack to now go through the aggregate.

Figure 1: A Gazebo built with Ashment:OPS concrete.

4.0 Conclusions and Recommendations

From the results and the discussions presented, it can be concluded that:

i. Ashment:OPS concrete with a density of about 1, 864.33kg/m^3 is a lightweight concrete.

ii. The 27.5N/mm^2 compressive strength of Ashment:OPS at 28 days is about 62% higher than the minimum required strength of 17N/mm^2 for structural lightweight concrete recommended by ASTM C330.
iii. Ashment:OPS concrete could decrease dead load by about 22%.
iv. Ashment:OPS concrete has a very good potential to reduce environmental pollution since the major constituents of the concrete; OPS and RHA, are from waste.

However, other properties of the Ashment:OPS concrete, such as thermal transmission, resistance to chloride attack as well as its behaviour under different conditions such as elevated temperatures, need to be studied. Economic benefits of utilising Ashment:OPS concrete need to be studied as well.

References

Achuenu, E., Olaoye, G. S., Ameh, E. O., Ujene, A. and Achuenu, F. (2005). A Study of Rice Husk Ash as Partial Replacement of Cement in Concrete with Periwinkle Shells as Aggregate: A Low-cost Building Material for the Niger Delta Area in Nigeria. Final Report submitted to National University Commission (NUC) under Centrally Coordinated Research Fund Scheme.

Achuenu, E, and Achuenu, S. A. (2010). A Self-Help/Partnership Initiative for Low-cost Housing Integrating Indigenous Building Materials in Nigeria: A Comprehensive Cost Evaluation. *Proceedings of Second International Conference on Construction in Developing Countries (ICCIDC-II) Themed: Advancing and Integrating Construction Education, Research and Practice.p98 -106.* August 3 - 5, 2010, Cairo, Egypt.

Akers, D. J. (2001). **Building Materials.** In F. S. Merritt & J. T. Ricketts (Eds); *Building Design and Construction Handbook. Sixth Edition. (pp 147 - 251).* New York, McGraw-Hill.

Al-Khalaf, M. N. and Yousif, H. A. (1984). Use of Rice Husk Ash in Concrete. *The International Journal of Cement Composites and Lightweight Concrete.* 6, (4), p241-248.

Allen, M. L. (2010). The Manufacture of a Cement Extender from Rice-Husks using a Basket-Burner. Prince of Songkla University, Thailand. the Prince of Songkla University and UNESCO. Accessed from www.journeytoforever.org on 01/03/2010.

ASTM C 29: 2000. Standard Test Method for Bulk and Voids in Aggregates. American Society for Testing and Materials.

ASTM C 128-15: 2000. Standard Test Method for Relative Density (Specific Gravity) and Absorption of Fine Aggregate. American Society for Testing and Materials.

ASTM C 567: 2000. Standard Test Method for Determining Density of Structural Lightweight Concrete. American Society for Testing and Materials.

ASTM C 330: 2001. Standard Specification for Lightweight Aggregates for Structural Concrete. American Society for Testing and Materials.

ASTM C 618-01. 2001. Specification for fly ash and Raw or Calcium Natural Pozzolana for use as a mineral admixture in Portland Cement Concrete. American Society for Testing and Materials.

Bouzoubaâ, N and Fournier, B. (2001). Concrete Incorporating Rice-Husk Ash: Compressive Strength and Chloride-Ion Penetrability. MATERIALS TECHNOLOGY LABORATORY. MTL 2001-5 (TR).

Chik, F. A. W., Jaya, R. P., Abu-Bakar, B. H., & Johari, M. Z. M. (2011). Effects of Rice Husk Ash to the Performance of Concrete. *International Journal of Applied Sciences and Technology.* 1. (3), 53 - 61.

Dashan, I.I. and Nwankwo, P.O. (2000). The Behaviour of Palm Kernel Shell Concrete at Elevated Temperatures. Nigeria Journal of Construction Technology and Management. 3, 1.

Duggal, S. K. (2012).**Building Materials.** Fourth Edition. New Age International Publishers, New Delhi. Pp 594.

Federal Ministry of Agriculture, (2014). National Report on Agricultural Performance Survey of 2007, 2008, 2009,2010, 2011 and 2012 Wet Seasons in Nigeria.

Food and Agriculture Organisation, (2013). World Statistics.

Indian Standards. (2000). Physical and Chemical Requirements for Pozzolana. IS: 3812.

Jalam, U. A., Sumaila, S. A. & Muhammed, S. I. (2014). Agricultural Solid Wastes Generation in Nigeria and their Recycling Potentials into Building Materials. *International Science Index.* 8. (11), 1386 - 1395

Mannan, M. A., and Ganapathy, C. (2001). Behaviour of Lightweight Concrete in Marine Environments. Proceedings of the International Conference on Ocean Engineering, Chennai, India. pp409-413.

Mannan, M. A., and Ganapathy, C. 2004. Concrete from an Agricultural Waste-Oil Palm Shell (OPS). *Building and Environment*. (39), pp 441-448.

Nilantha, B.G.P., Jiffry, I., Kumara, Y.S. and Subashi, G.H.M.J. (2010). Structural and Thermal Performances of Rice Husk Ash (RHA) Based Sand Cement Block. Proceedings of the International Conference on Sustainable Built Environment (ICSBE-2010), Kandy, 13-14 December 2010. p138 - 144.

Olivier, P. A. (2008). The Rice Hull House. Accessed on 12/03/2008 from:

http://www.esrla.com/shotgun/frame.htm

Oliveira, M. O., Neto, J. M., Inocencio, M. C., Ando-Junior, O. H., Bretas, A. S. and Perrone, O. E. (2012). Viability Study for Use of Rice Husk in Electricity Generation by Biomass. A paper presented at the International Conference on Renewable Energies and Power Quality (ICREPQ'12), Santiago de Compostela (Spain), 28th to 30th March, 2012.

Osha, O. A., Aroke, U. O. & Aliyu, U. M. (2005). Atmospheric Pollution by Dust Emissions From Cement Manufacturing Operations: Case Study of Ashaka Works, Gombe State. *Journal of Environmental Sciences*. 9. (2),53-61.

Oviasogie, P. O., Odewale, J. O., Aisueni, N. O., Eguagegie, E. I., Brown, G. and Okoh- Oboh, E. (2013). Production, Utilisation and Acceptability of Organic Fertilisers Using Palm and Shea Trees as Sources of Biomass. *African Journal of Agricultural Research. 8(27).* pp 3483 - 3494.

Oyejobi, D. O., Abdulkadir, T. S., Yusuf, I. T. & Badiru, M. J. (2012). Effects of Palm Kernel Shells Sizes and Mix Ratios on Lightweight Concrete. *Journal of Research Information in Civil Engineering.* 9. (2), 217 - 226.

Oyekan, G. L. & Kamiyo, O. M. (2007). Effect of Nigerian Rice Husk Ash on Some Engineering Properties of Concrete and Sandcrete Blocks. *Proceedings of the 32nd Conference on Our World in Concrete & Structures* held on 28 - 29 August, 2007. Singapore.

Oyekan, G. L. & Kamiyo, O. M. (2011). A Study on the Engineering Properties of Sandcrete Blocks Produced with Rice Husk Ash Blended Cement. *Journal of Engineering and Technology Research.* 3. (3), 88 - 98.

Oyetola, E. B. & Abdullahi, M. (2009).The Use of Rice Husk Ash in Low - Cost Sandcrete Block Production. Accessed on 01/03/2009 from http://lejpt.academicdirect.org/A08/58_70.htm.

Rahman, M. A. (1987). Use of Rice Husk Ash in Sandcrete Blocks for Masonry Units. *Materials and Structures.* 20. (5), 361-366.

Rukzon, S and Chindaprasirt, P. (2008). Use of Waste Ash from Various by-product Materials in Increasing the Durability of Mortar. *Songklanakarin Journal of Science and Technology.* 30 (3), 485-489.

Teo, D. C. L., Mannan, M. A., and Kurian, V. J. (2005). Utilisation of Solid Waste Oil Palm Shell (OPS) in Concrete Production. Proceedings of the International Conference on Natural Resources and Environmental Management, Kuching, Sarawak, Malaysia. pp135 - 140.

Teo, D.C.L, Mannan, M. A. & Kurian, V. J. (2006). Structural Concrete Using Oil Palm Shell (OPS) as Lightweight Aggregate. *Turkish Journal of Engineering and Environmental Science.* 30. 251 - 257.

World Index (2014). World Production of Palm Oil. Accessed at: http://www.indexmundi.com/agriculture/?commodity=palm-oil&graph=production on 2014-08-07.