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Characteristics of Artificial Lightweight Aggregates Produced from Palm Oil Fuel Ash and Fly Ash Using Cold-Bonding

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Abstract

Crushed stone aggregates are commonly used in the construction industries and can lead to the depletion of natural resources if used excessively. To avoid this from happening, the incorporation of wastes and by-products as alternative materials in artificial lightweight aggregates (ALWA) production has become a major area of interest recently. In Malaysia, palm oil fuel ash (POFA) and fly ash (FA) are by-products which are abundantly available and could contribute towards environmental pollution if not properly managed. The main aim of this research is to determine the characteristics of ALWA made from POFA and FA using cold bonding method. In this research, two different types of NaOH molarity (8M and 10M) and a constant ratio of sodium silicate to sodium hydroxide (1:1) were used as alkali activators. The percentage of POFA to FA used in this research was 80% and 20%, respectively. From the results obtained, it was observed that the bulk density and particle density of POFA FA aggregates increase as the molarity of NaOH increases. On the other hand, the water absorption of the POFA FA aggregates was found to decrease from 8.3 to 7.1% when the molarity of NaOH was increased from 8M to 10M. The experimental results of the crushing strength show that POFA FA aggregates with higher molarity of NaOH (10M) shows a better crushing strength as compared to POFA FA aggregate with lower molarity of NaOH (8M).

Keywords: *Lightweight Aggregates, By-products, Crushing Strength, Water Absorption.*

1. Introduction

In Malaysia, rapid growth of the construction industry in conjunction with economic growth has led to an increase in the production and consumption of construction materials such as rock material (natural aggregate) to fulfill its demand nowadays. Concrete is one of the most commonly used material in the construction industry. Since concrete is made up of approximately 70% aggregate, massive production of these naturally occurring aggregates is required and consequently contributes towards environmental degradation. Natural aggregates obtained by adopting the blasting method at quarry sites may cause hazard to livelihood and the surrounding earth structure. In Malaysia, about 300 quarry sites extract a total of 110,339,000 tonnes of aggregates in year 2012 [1]. Although the source of natural aggregate is still adequate for the current situation, however, aggressive consumption of non-renewable aggregates can cause depletion in the future if the planning of natural aggregate exploitation is inappropriately done.

At the same time, industrial solid waste pollution has become a serious environmental problem in the world. The growth of industries is increasing due to the rapid change in population, and as a result, a large amount of industrial solid wastes is generated and dumped in landfills without any profitable return. Fly ash (FA) and palm oil fuel ash (POFA) are industrial waste materials commonly found in Malaysia. FA is a finely divided ash collected from the combustion of pulverised coal in electric power generating plants. Currently, about 42.5% of electricity in Malaysia is produced by means of coal firing, which consumes about 8 million tonnes of coal in year 2015 [2]. Since fly ash represents approximately 58% of coal combustion products as waste material [3], it is estimated that a total of 4.7 million tonnes of fly ash was generated in the year 2015. FA has been regarded as one of the 27 products in the family of common cements as stated in BS EN 197-1 [4] and it has been identified as 'pozzolanic material' used to partially replace ordinary Portland cement (OPC) in cement production. In Malaysia, FA has been used in the construction of some structures which includes the Petronas Twin Towers, Second Malaysia-Singapore Causeway [5], and roller compacted concrete dam [6]. However, the usage of FA is still not widely applied in the construction industry. On the other hand, POFA is an ash-formed waste material produced from the burning of palm oil fibre and palm oil shell as fuel in the boilers of the palm oil industry. In Malaysia, oil palm serves as one of the most important crops which accounts for 37% of world palm oil exports [7]. Based on the statistics recorded by the Malaysian Palm Oil Board [8], the total oil palm planted area in Malaysia is about 5.81 million hectares in the year 2014. The total amount of fresh fruit bunches processed by over 400 palm oil mills is approximately 103.94 million tonnes (17.89 tonnes per hectares) [8]. A fresh fruit bunch consists of approximately 26% mesocarp oil, 21% kernel nut, 10% kernel shell, 30% palm empty fruit bunch, 15% mesocarp fibre [9]. Therefore, it is estimated that about 57.17 million tonnes of solid-waste by products are produced in the year 2017. Since POFA is a product from the burning of palm oil kernel shell and palm oil fibre, which is approximately 5% of these solid waste by-product [10], approximately 2.8 million tonnes of POFA is estimated to be discharged in Malaysia. In particular, Sarawak is the second largest palm planted area in Malaysia, with an estimated 0.5 million tonnes of POFA generated in 2017 alone. As the quantity of POFA discharged is expected to increase annually, the allocation of transportation costs and landfills for the disposal of POFA are not effective ways to manage this waste as it may lead to environmental problems in the future. To address the issue of environmental impact and as a step to preserve the natural aggregates in Malaysia, artificial lightweight aggregate (ALWA) incorporating the combined use of POFA and FA as source materials is a highly recommended solution.

ALWA can be manufactured from raw materials either through sintering or cold bonding. Sintering is a process whereby the pellets are subjected to elevated temperatures of generally up to 1200°C in a rotary-kiln based on atomic diffusion between the treated materials [11][12]. On the contrary, cold bonding is a process whereby the pellets are hardened by different curing processes such as normal water curing, steam curing and autoclaving at ambient temperature to attain the strength [11]. Cold bonding is a minimal energy utilisation method and thus, is more environmental friendly as compared to the sintering method, in which it is requires huge amount of energy. Therefore, cold bonding technology is an alternative method in ALWA production with minimum energy consumption and low environment impact. In cold bonding, sources of calcium hydroxide ($Ca(OH)2$) like Portland cement play an important role in pozzolanic reaction as it can react with pozzolanic ash materials to produce a water-resistant bonding/matrix bonding at ordinary temperatures. Fly ash, bottom ash and ground granulated blast furnace slag are pozzolanic ash materials normally used and combined with Portland cement in ALWA production through cold bonding which have been reported in recent years [13]-[15]. However, the over-dependence on Portland cement in ALWA development is not an eco-friendly approach as it would give off carbon dioxide during cement production. More recently, alkali activated binder, has emerged as an alternative to Portland cement binder through alkaline activation process, and this has been used in ALWA production [16]-[19]. Alkaline activation is a chemical process whereby the alumino-silicate based ash material is mixed with an alkaline activator solution to produce an alkali activated binder, called alumino-silicate gel, which gives good mechanical and environmental performance [20]. The mixture of sodium hydroxide (NaOH) with sodium silicate (Na2SiO3) is the most commonly used alkaline activator solution [21] as these two components are widely available and inexpensive. In alkaline activation, NaOH solution is used as a function to dissolute the alumino-silicate materials, while the Na2SiO3 is used as binder, dispersant as well as plasticiser [22].

In this research, the characteristics of using both POFA and FA to produce a new type of ALWA through the cold bonding method using alkaline activator is studied. The performance characteristics of the ALWA were investigated through bulk density, water absorption and crushing strength.

2. Materials and Methods

2.1 Raw materials used

FA, POFA, of sodium hydroxide (NaOH) and sodium silicate (Na2SiO3) were used in this study. All materials were obtained locally. The combination of NaOH and industrial grade Na2SiO3 were used as the binders in this study.

2.2 Preparation of raw material and pellets

The freshly collected POFA was first dried in an electric oven at a temperature of 110 ± 5 ºC for 24 hours to remove the moisture in the POFA. Then, the POFA was sieved through a 300 μm sieve to separate the larger particles and other impurities. Next, POFA was ground in a blender machine for about 5 minutes. Before being used, the ground POFA was kept in an airtight container separately to prevent it from being exposed to moisture. The raw materials, POFA and FA were mixed homogeneously in a tray. The percentage of POFA to FA used in this study was 80% and 20%, respectively. The molarities of sodium hydroxide used were 8M and 10M and ratio of sodium silicate to sodium hydroxide used was 1:1 in this study. Pelletisation was carried out in a pelletiser disc of 570 mm diameter, with an inclined angle of 74° and a speed of 55 rpm. The disc design was based on the findings of a previous study [23]. After production, these pellets were cured in a sealed container for 28 days. Figure 1 shows the produced aggregates containing POFA and FA after the curing period. These aggregates are called POFA FA aggregates hereinafter.

Fig 1. ALWA produced using both POFA and FA after 28 days of curing

2.3 Testing methods

At the end of the curing period, the properties of aggregate were analysed, which includes particle density, bulk density, water absorption, and crushing strength. The particle density and bulk density were conducted based on BS EN 1097-6 [24] and BS EN 1097-3 [25], respectively to determine if the produced aggregates satisfy the requirements as lightweight aggregate for concrete making. Water absorption testing on the aggregate were conducted based on BS EN 1097-6 [24]. The individual crushing strength of aggregates were measured by compressing the individual aggregate in the diametrical direction with two parallel plates using an unconfined compressive strength (UCS) testing machine. The individual crushing strength, σ of aggregates is given by:

$$\sigma = \frac{2.8 \times P}{\pi \times X^2} \quad (1)$$

where the P is fracture point load and X is the distance between the two parallel plates, that is the diameter of aggregate. The crushing strength of the aggregates was determined at 7, 14, and 28 days.

3. Results and Discussion

Table 1 and Figure 2 show the results of physical characteristic of POFA FA aggregates namely bulk density, particle density and water absorption, and the strength development of POFA FA aggregates, respectively. Based on the standard stated in BS EN 13055-1 [26], lightweight aggregate is defined as a granular material with a particle density not exceeding 2000 kg/m3 or a loose bulk density not exceeding 1200 kg/m3. Therefore, all the aggregates satisfied the requirements as lightweight aggregates based on results in Table 1. It was found that both bulk density and particle density increase when the molarity of NaOH is increase, which is from 1043.25 to 1097.40 kg/m3 and 1940.28 to 1980.41 kg/m3 respectively. This is because the high molarity of NaOH caused greater dissolution process due to the leaching of silica and alumina which contributed to the increases in the geopolymerisation reaction, resulting in denser geopolymer microstructure [27]. In terms of water absorption of the POFA FA aggregates, the values decreased from 8.3 to 7.1% when the molarity of NaOH is increased from 8M to 10M respectively. This may be due to the increased molarity of NaOH which improves the geopolymerisation mechanism and microstructure composition [28].

Table 1 Bulk density, particle density and water absorption of POFA FA aggregates

Physical characteristics of POFA FA aggregates	Molarity of NaOH	
	8M	10M
Bulk density (kg/m^3)	1043.25	1097.40
Particle density (kg/m^3)	1940.28	1980.41
Water absorption (%)	8.3	7.1

Based on Figure 2, the results show that all the aggregates exhibit increment in strength development as the molarity of NaOH is increased. The higher crushing strength was observed at 10M of NaOH molarity with 7.8 MPa in 28 days while the lower crushing strength was obtained at 8M of NaOH molarity with 6.8 MPa in 28 days. It was previously reported that the concentration of NaOH solution affects the dissolution ability of raw materials and accelerates the condensation of the monomer [29]. Hence, the bonding strength of the geopolymer increases.

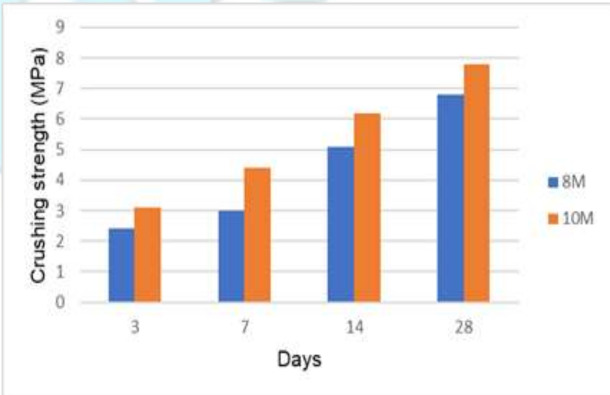

Fig 2. The strength development of POFA FA aggregates for different molarity of NaOH.

4. Conclusions

Based on the results obtained from the current laboratory investigation, the following conclusions can be drawn:

i. The greater the molarity of NaOH used during the production, the higher the bulk density and particle density of POFA FA aggregates obtained.

ii. An increase in the concentration (molarity) of NaOH used, leads to a reduction in the water absorption values of POFA FA aggregates.

iii. The crushing strength of all aggregates were found to increase from 3 days to 28 days regardless of NaOH concentration. Aggregates with higher molarity of NaOH (10M) show better crushing strength as compared to aggregates with lower molarity of NaOH (8M).

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References

[1] Tse, P. K. (2015). The Mineral Industry of Malaysia. Minerals Yearbook-Area Reports: International Review: 2013, Asia and Pacific, 3, 17.1-17.7.

[2] Malaysia Energy Information Hub (MEIH). (2017). Malaysia Energy Statistics Handbook. Available from: http://meih.st.gov.my/documents/10620/b1849938-e2e9-49fe-a789-9240df14cd75

[3] Kalyoncu, R. S. (2000). Coal Combustion Products. US Department of the Interior, US Geological Survey, 20.1-20.5.

[4] BS EN 197-1. (2011). Cement: Composition, Specifications and Conformity Criteria for Common Cements. London: British Standard Institution.

[5] Kidav, E. U., Soo, T. P., Sirivivatnanon, V., & Khatri, R. (2001). Advances in Malaysian Fly Ash Concrete Technology. Special Publication, 199, 343-360.

[6] Zulkifli, A. R., Hamid, A. R. A., Arshad, M. F., & Ahmad, J. (2015). Construction of Roller Compacted Concrete Dam in Malaysia: A Case Study at Batu Hampar Dam. In Proceedings of the International Civil and Infrastructure Engineering Conference 2014, 727-739.

[7] Malaysian Palm Oil Council (MPOC). (2016). Annual Report 2016. Available from: http://www.mpoc.org.my/upload/AR%202016%20without%20FS.pdf

[8] Malaysian Palm Oil Board (MPOB). (2017). Overview of the Malaysian Oil Palm Industry. Available from: http://bepi.mpob.gov.my/images/overview/Overview_of_Industry_2017.pdf

[9] Corley, R. H. V., & Tinker, P. B. (2003). The Oil Palm. 4th ed. Berlin: Blackwell Publishing.

[10] Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2004). Utilization of Palm Oil Fuel Ash in High-Strength Concrete. Journal of Materials in Civil Engineering, American Society of Civil Engineers (ASCE), 16(6), 623-628.

[11] Sivakumar, A., & Gomathi, P. (2012). Pelletized Fly Ash Lightweight Aggregate Concrete: A Promising Material. Journal of Civil Engineering and Construction Technology, 3(2), 42-48.

[12] Terzić, A., Pezo, L., Mitić, V., & Radojević, Z. (2015). Artificial Fly Ash Based Aggregates Properties Influence on Lightweight Concrete Performances. Ceramics International, 41(2), 2714–2726.

[13] Geetha, S., & Ramamurthy, K. (2010). Environmental Friendly Technology of Cold-Bonded Bottom Ash Aggregate Manufacture Through Chemical Activation. Journal of Cleaner Production, 18(15), 1563-1569.

[14] Gesoğlu, M., Güneyisi, E., Mahmood, S. F., Öz, H. Ö., & Mermerdaş, K. (2012). Recycling Ground Granulated Blast Furnace Slag as Cold Bonded Artificial Aggregate Partially Used in Self-Compacting Concrete. Journal of Hazardous Materials, 235, 352-358.

[15] Gesoğlu, M., Güneyisi, E., Alzeebaree, R., & Mermerdaş, K. (2013). Effect of Silica Fume and Steel Fiber on the Mechanical Properties of The Concretes Produced with Cold Bonded Fly Ash Aggregates. Construction and Building Materials, 40, 982-990.

[16] Bui, L. A. T., Hwang, C. L., Chen, C. T., Lin, K. L., & Hsieh, M. Y. (2012). Manufacture and Performance of Cold Bonded Lightweight Aggregate Using Alkaline Activators for High Performance Concrete. Construction and Building Materials, 35, 1056-1062.

[17] Gesoğlu, M., Özturan, T., & Güneyisi, E. (2006). Effects of Cold-Bonded Fly Ash Aggregate Properties on The Shrinkage Cracking of Lightweight Concretes. Cement and Concrete Composites, 28(7), 598-605.

[18] Gesoğlu, M., Özturan, T., & Güneyisi, E. (2007). Effects of Fly Ash Properties on Characteristics of Cold-Bonded Fly Ash Lightweight Aggregates. Construction and Building Materials, 21(9), 1869-1878.

[19] Jo, B. W., Park, S. K., & Park, J. B. (2007). Properties of Concrete Made with Alkali-Activated Fly Ash Lightweight Aggregate (AFLA). Cement and Concrete composites, 29(2), 128-135.

[20] Palomo, A., & Fernández-Jiménez, A. (2011). Alkaline Activation, Procedure for Transforming Fly Ash into New Materials. Part I: Applications. In World of Coal Ash (WOCA) Conference, 1-14.

[21] Pacheco-Torgal, F., Castro-Gomes, J., & Jalali, S. (2008). Alkali-Activated Binders: A Review. Part 2. About Materials and Binders Manufacture. Construction and Building Materials, 22(7), 1315-1322.

[22] Komnitsas, K., & Zaharaki, D. (2007). Geopolymerisation: A Review and Prospects for the Minerals Industry. Minerals Engineering, 20(14), 1261-1277.

[23] Baykal, G., & Döven, A. G. (2000). Utilization of Fly Ash by Pelletization Process; Theory, Application Areas and Research Results. Resources, Conservation and Recycling, 30(1), 59-77.

[24] BS EN 1097-6. (2013). Tests for Mechanical and Physical Properties of Aggregates: Determination of Particle Density and Water Absorption. London: British Standard Institution.

[25] BS EN 1097-3. (1998). Tests for Mechanical and Physical Properties of Aggregates: Determination of Loose Bulk Density and Voids. London: British Standard Institution.
[26] BS EN 13055-1. (2002). Lightweight Aggregates for Concrete, Mortar and Grout. London: British Standard Institution.
[27] Chindaprasirt, P., Jaturapitakkul, C., Chalee, W., & Rattanasak, U. (2009). Comparative Study on The Characteristics of Fly Ash and Bottom Ash Geopolymers. Waste Management, 29(2), 539-543.
[28] Huseien, G. F., Mirza, J. A. H. A. N. G. I. R., Ismail, M. O. H. A. M. M. A. D., Hussin, M. W., Arrifin, M. A. M., & Hussein, A. A. (2016). The Effect of Sodium Hydroxide Molarity and Other Parameters on Water Absorption of Geopolymer Mortars. Indian Journal of Science and Technology, 9(48).
[29] Wang, H., Li, H., & Yan, F. (2005). Synthesis and Mechanical Properties of Metakaolinite-Based Geopolymer. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 268(1-3), 1-6.