Utilization of Palm Oil Boiler Ash (POBA) as Geopolymer Material for Industrialized Building System (IBS) Application

by

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LIST OF ABBREVIATIONS

Al	Alumina
Al_2O_3	Aluminum Oxide
ASTM	American Society for Testing and Materials
BAG	Blended Ash Geopolymer
BS	British Standard
Ca	Calcium
CaO	Calcium Oxide
CIDB	Construction Industry Development Board
CO_2	Carbon Dioxide
CSH	Calcium Silicate Hydrate
FTIR	Fourier Transform Infrared Spectroscopy
GGBS	Ground Granulated Blast Furnace Slag
IBS	Industrialized Building System
K	Potassium
KOH	Potassium Hydroxide
M	Molar Ratio
MJ	Mega Joule
MgO	Magnesium Oxide
mm	Milimeter
MPa	Megapascal
Na	Sodium
Na_2SiO_3	Sodium Silicate
NaOH	Sodium Hydroxide

OH	Hydroxide
OPC	Ordinary Portland Cement
PFA	Pulverized Fly Ash
POBA	Palm Oil Boiler Ash
POFA	Palm Oil Fuel Ash
PSA	Particle Size Analysis
S/L	Solid/Liquid
SEM	Scanning Electron Microscopy
Si	Silica
SiO_2	Silica Oxide
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

Kajian Penggunaan Abu Dandang Kelapa Sawit (POBA) Sebagai Bahan Geopolimer untuk Aplikasi Sistem Bangunan Berindustri (IBS)

ABSTRAK

Penghasilan sisa pepejal daripada proses pengekstrakan minyak kelapa sawit meningkat setiap tahun. Abu dandang kelapa sawit (POBA) atau dikenali juga sebagai abu bawahan terhasil daripada proses pembakaran sisa pepejal kelapa sawit seperti serat, tempurung dan juga tandan kelapa sawit. Penghasilan POBA dianggarkan sebanyak 4 juta ton/tahun di mana selalunya ia digunakan sebagai baja. Geopolimer atau pengikat aktif-alkali terhasil daripada proses sintesis bahan yang mengandungi silika dan alumina dengan larutan pengaktif alkali. Kajian ini telah dilaksanakan untuk menghasilkan pes geopolimer dan juga bata geopolimer dan bata IBS dengan menggunakan proses pengeopolimeran. Untuk kajian pes geopolimer, terdapat 4 parameter utama yang telah dikaji iaitu kesan kemolaran NaOH, nisbah S/L serta Na_2SiO_3/NaOH dan kesan suhu pengawetan. Kemudian, kesan setiap parameter ini terhadap penghasilan pes geopolimer akan dianalisa menggunakan kekuatan mampatan, XRD, FTIR dan SEM. Manakala untuk rekabentuk bata geopolimer dan bata IBS, nisbah optimum (kemolaran NaOH, nisbah S/L serta Na_2SiO_3/NaOH dan kesan suhu pengawetan) daripada penghasilan geopolimer pes digunakan untuk menghasilkan bata. Nisbah POBA kepada pasir yang digunakan semasa penghasilan bata geopolimer dan bata IBS untuk kajian ini adalah 1:3. Prestasi bata geopolimer dan bata IBS di analisa dari segi kekuatan mampatan, kadar penyerapan air dan juga ketumpatan bata pada masa pematangan yang berbeza iaitu hari ke-1, ke-3, ke-7, ke-28 dan ke-60. Daripada kajian ini, kekuatan mampatan pes geopolimer yang maksimum diperolehi pada kemolaran NaOH 14M, nisbah S/L serta Na_2SiO_3/NaOH pada 1.5 dan 2.5 dengan suhu pengawetan 80 °C. Melalui analisa XRD, kewujudan albite iaitu gel aluminasilikat menghasilkan pes geopolimer dengan kekuatan yang lebih baik. Di samping itu, penghasilan bata geopolimer menggunakan POBA menunjukkan peningkatan kekuatan dengan masa dimana kekuatan maksimum diperoleh hingga 16.1 MPa (hari ke-60). Bata ini mempunyai ketumpatan dalam julat 1615 kg/m^3 - 1742 kg/m^3 dan boleh diklasifikasikan sebagai bata berat sederhana untuk bata tanpa beban mengikut standard ASTM C129. Manakala, kadar penyerapan adalah dalam julat 6.8% - 12.2% dan ia adalah kurang daripada had 17% yang ditetapkan dalam spesifikasi ASTM C90. Untuk bata IBS, kekuatan mampatan maksimum pada hari ke-60 adalah 14.3 MPa. Untuk bata IBS, kekuatan mampatan 14.3 MPa dicatatkan pada hari ke-60. Terdapat perbezaan kekuatan mampatan bagi bata IBS kerana kewujudan lidah (tongue) dan lekuk (groove) pada permukaan bata ini yang menghasilkan kekuatan lebih rendah. Bata IBS diklasifikasikan sebagai bata berat sederhana mengikut standard ASTM C129 dengan ketumpatan 1792 kg/m^3 - 1894 kg/m^3 dan kadar penyerapan air dalam julat 8.7% - 14.5%.

Utilization of Palm Oil Boiler Ash (POBA) as Geopolymer Material for Industrialized Building System (IBS) Application

ABSTRACT

The increment of palm oil waste from palm oil extraction increased every year in Malaysia. Palm oil boiler ash (POBA) or bottom ash is one of the waste material from the palm oil industry where it was obtained from the burning process of solid waste such as empty fruit bunch, shell and fiber. The production of POBA was estimated about 4 million tonnes/year where it was usually used as fertilizer. Geopolymer or alkali-activated binder is produced by synthesizing aluminosilicate source materials with an alkaline activator solution. This study has been conducted to produce POBA geopolymer paste and brick and IBS brick by using geopolimerization process. The parameters for the geopolymer paste production included the NaOH concentration, ratios of S/L as well as Na_2SiO_3/NaOH and curing temperature. Then, the effect of each parameter towards production of geopolymer paste was evaluated using compressive strength, XRD, FTIR, and SEM. Meanwhile, for mix design of geopolymer brick and IBS brick, the optimum ratio (NaOH concentration, ratio of S/L and Na_2SiO_3/NaOH and curing temperature) from the geopolymer paste production has been used to produce the bricks. The ratio of POBA-to-sand for geopolymer brick and IBS brick for this study was 1:3. The performance of geopolymer brick and IBS brick were analyzed in term of compressive strength, water absorption and density at different aging period, which is 1st, 3rd, 7th, 28th and 60th days. From this study, the maximum compressive strength of geopolymer paste was achieved at NaOH concentration 14M, ratio of S/L as well as Na_2SiO_3/NaOH at 1.50 and 2.5 respectively and curing temperature at 80 °C. From the XRD analysis, the existence of albite which is aluminosilicate gel leads to better strength of geopolymer paste. Besides that, for the geopolymer brick produced using POBA, showed an increment in strength with times where the maximum strength obtained was up to 16.1 MPa (60th days). The density of this brick was in the range 1615 kg/m^3 to 1742 kg/m^3 and can be classified into medium weight for non-loading brick according to ASTM C129 (2013). As for the water absorption, the range was 6.8% to 12.2%, which is less than limit (17 %) of ASTM C90 specification. For IBS brick, the maximum compressive strength at 60th days was 14.3 MPa. There are slightly different strength of IBS brick, which is due to the existence of tongue and groove on the surface of IBS brick thus leads to lower strength. The IBS brick was classified as medium weight brick according to ASTM C129 with density a in the range 1792 kg/m^3 to 1894 kg/m^3 and water absorption 8.7% to 14.5%.

CHAPTER 1

INTRODUCTION

1.1 Geopolymer for Green Environment

The production of ordinary Portland cement (OPC) as the main binder for the construction industry has contributed about 7% of total worldwide carbon dioxide (CO_2) emissions to the earth's atmosphere (Ali, et. al., 2011). Nowadays, the world was in urge to reduce CO_2 emission by introducing environmental friendly cement or known as geopolymer. The term geopolymer was introduced in 1978 by Davidovits where it was produced by activating silicon (Si) and aluminum (Al) in source materials of geological origin or by product materials such as fly ash with alkaline activators (Davidovits, 1999).

Before this, geopolymer was known as alkali-activated binder and in 1940s Purdon was the researcher that investigated about the activation of blast furnace slag with sodium hydroxide (NaOH) (Pacheco-Torgal, et. al., 2008a). Meanwhile, in 1959 Glukhovsky was the researcher that explored the utilization of binders in ancient Roman and Egyptian construction (Duxson, et. al., 2007a). It was found that the construction materials were composed of alumino-silicate calcium hydrates which is similar to the OPC and has a crystalline phase of analcite which is natural rock. Then, he terms his finding as 'soil cement'.

Geopolymer was classified as inorganic binders with a chemical composition similar to natural zeolite but it has amorphous microstructure instead of crystalline (Palomo, et. al., 1999a; Xu & van Deventer, 2000a). Moreover, the binder reaction of geopolymer was completely different compared to OPC. For OPC, the strength depends on the formation of calcium-silicate hydrate but for geopolymer it depends on the polycondensation of Si and Al precursor and also high alkaline content (van Jaarsveld, et. al., 2002).

The potential of geopolymer to replace OPC was supported by the fact that there is abundant industrial waste from many industries which are suitable to be used as source material for geopolymer, where these wastes are generating problems in term of finding solution for disposal purposes. The materials that have been used as a main source for geopolymer were fly ash, ground granulated blast furnace slag (GGBS), metakaolin, kaolin, palm oil fuel ash (POFA) and volcanic ashes. As such, by using this by-product as source material for geopolymer it can reduce the environmental impact through recycling.

The geopolymer possess excellent properties as found by previous researchers such as high compressive strength, acid resistance, fire resistance, low shrinkage and low thermal conductivity (Palomo, et. al., 1999b; Duxson, et. al., 2007a; Zhang, et. al., 2010; Duxson, et. al., 2007b, Temuujin, et. al., 2011).

This research elaborates the utilization of palm oil boiler ash (POBA) in geopolymer production and also its performance as geopolymer bricks and IBS bricks, since currently there is no research about the consumption of POBA in geopolymer.

1.2 Palm Oil Fuel Ash (POFA)

Malaysia is the second largest producers of palm oil in the world where about 5.23 million hectares of oil palm planted area and the total exports of palm oil product was about 25.70 million tones (Malaysian Palm Oil Board, 2013a). The success in palm oil industry in Malaysia was due to tropical country which possesses hot and wet weather for an entire year. The growth of oil palm plantation in Malaysia has been increasing rapidly from year 1990 to 2011 as described in Figure 1.1 and Figure 1.2 (Malaysian Palm Oil Council, 2013). In 1990, only 2.3 million hectares of land were used for oil palm plantation, however in 2011, 5.0 million hectares of land has been used as oil palm plantation to fulfil the high demand of palm oil.

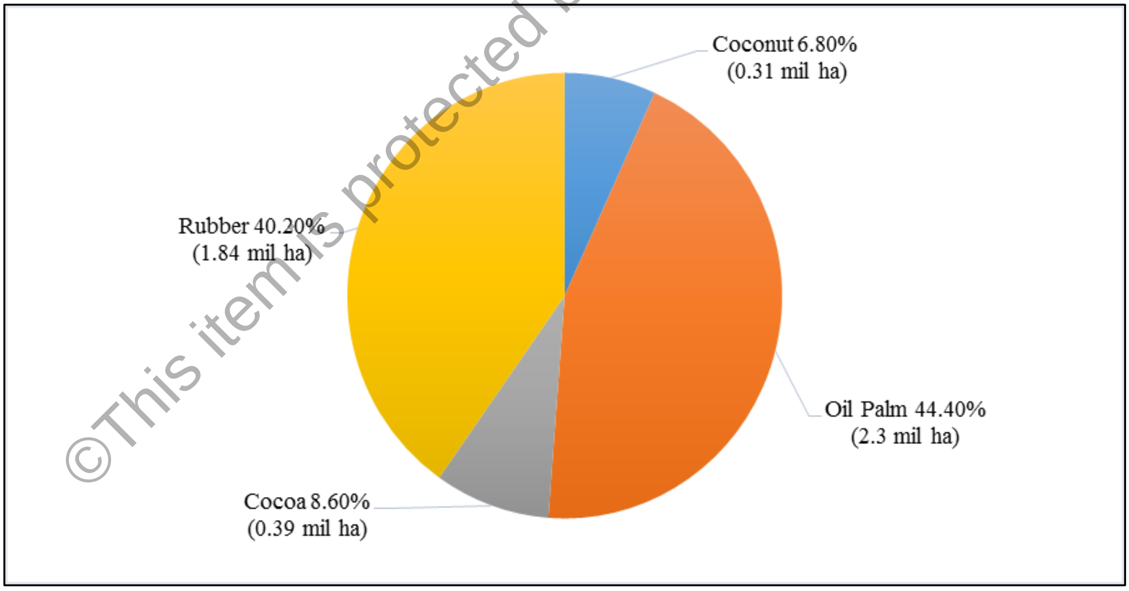

Figure 1.1: Major of tree crops in Malaysia in 1990 (Malaysian Palm Oil Council, 2013)

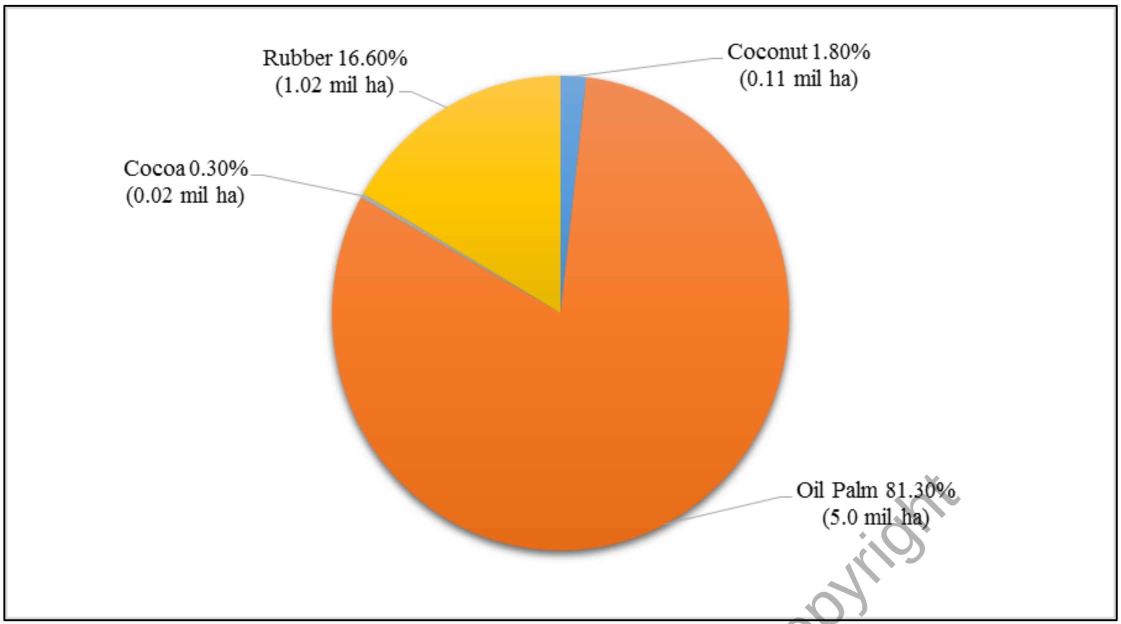

Figure 1.2: Major of tree crops in Malaysia in 2011 (Malaysian Palm Oil Council, 2013)

With the increasing of oil palm plantation every year, the waste material also increased. The solid waste from palm oil extraction such as empty fruit bunch, fiber and shell was estimated about 44 million tones/years (Yoon Lin & Sohei, 2013). The details of total production were described in Figure 1.3 (Malaysian Palm Oil Board, 2013b).

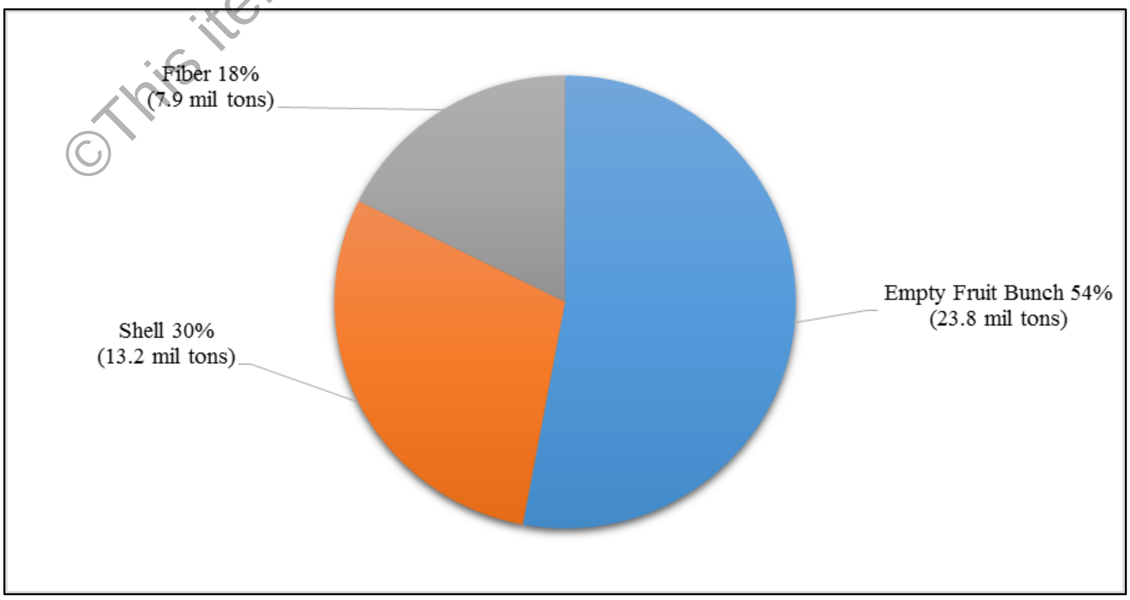

Figure 1.3: Solid waste from palm oil extraction (Malaysian Palm Oil Board, 2013b)

These solid waste was burnt in the boiler in order to produce steam for electricity generation. From this burning process, two types of ash were obtained which is palm oil fuel ash (POFA) and palm oil boiler ash (POBA). The production of POFA was estimated about 3 million tones/year (Malaysian Palm Oil Board, 2013c) and it has finer particles size which is similar with fly ash. Usually POFA was used as cement replacement material and admixture in concrete production due to finer particles (Tangchirapat, et. al., 2007).

1.3 Palm Oil Boiler Ash (POBA)

POBA consists larger particles of clinkers and ash, thus it also known as bottom ash. The production of POBA was estimated over 4 million tones/year (Boey, et. al., 2011) where it was usually used as fertilizer, roads networks in the palm oil mill (Vijaya, et. al., 2008) and the rest was dumped around the factory. Figure 1.4 showed the processing of POFA and POBA in the boiler.

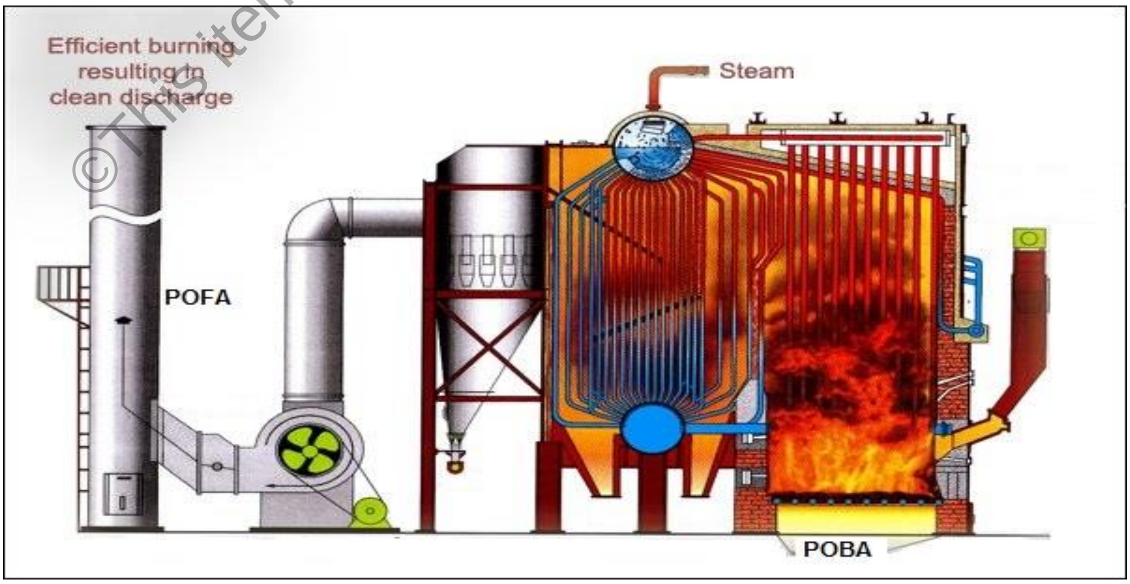

Figure 1.4: Process of POBA and POFA at palm oil mill (http://axisro.com/sentralind/products_biomas.html, 2014)

1.4 Bricks

The brick manufacturing generally produced using clay with high temperature firing process or from OPC (cement bricks) which lead to high energy consumption and also CO_2 emissions. Bricks were one of the important constituents used in construction and building materials for a long time where the production of bricks was estimated about 1500 billion units and the demands for bricks still increased each year (http://hablakilns.com/industry.htm, 16 September 2014). The details of bricks production, according to country was shown in Table 1.1.

Table 1.1: Worldwide brick production (http://hablakilns.com/industry.htm, 2014)

Country	**Bricks Production (billion)**
China	1000
India	200
Pakistan	45
Vietnam	25
Bangladesh	17
Nepal	6
Other Asia Countries	7
USA	8
UK	4
Australia	2
Other Countries	186
Total World Production	**1500**

The production of clay bricks has involved high temperature kiln firing (consume high energy) and also depletion of raw material by excavating clay. Reddy and Jagadish (2003) estimated that about 3.75 MJ to 4.75 MJ thermal energy was used to produce each clay brick. Meanwhile, for OPC bricks which used OPC and also fine aggregates as main materials also consume large amounts of energy and greenhouse gas (CO_2) emission to the environment. As such for more sustainable environment, many researchers had studied about the consumption of waste materials such as fly ash (Lingling, et. al., 2005), mine tailings (Chen, et. al., 2011), and slags (Lin, 2006) to produce bricks.

1.5 Industrialized Building Systems (IBS)

Industrialized Building Systems (IBS) can be defined as a construction technique where the components are manufactured in a controlled environment (on or off site), transported, positioned and installed into structure with minimal additional site works (CIDB, 2003). The building components such as wall, floor slab, beam, column and staircase were an example of IBS product that has been produced in a factory (Trikha, 1999). In Malaysia, Construction Industry Development Board (CIDB) has classified IBS into five categories as follows:

- Precast concrete systems
- Formwork systems
- Steel framing systems
- Prefabricated timber framing systems
- Block work systems

Nowadays, the applications of IBS in Malaysia was encouraged in order to reduce the construction period as well as foreign labor. With the increasing population, the demand for residential buildings also increased. From year 1995 to 2020 there are about 8,850,554 units (including 4,964,560 units of new housing units) were required (Syariazulfa, et. al., 2013). So far the implementation of IBS in government project from 2006 to 2010 approximately 320 projects (Kamarul, et. al., 2010).

1.6 Problem Statement

The waste material from the palm oil industry has been increasing each year since Malaysia was one of the world largest exporters of palm oil, thus the ash produced from combustion of palm fiber, kernel shells and empty fruit bunch in the boiler also increased. Nowadays, there are many researches about the utilization of POFA which has fine particles and pozzolanic properties. However, for POBA which has a larger particle size, the only effort that has been applied in order to reduce the amount is by using it as fertilizer for agricultural propose. The use of POBA as fertilizer also may lead to other environmental problem because this application was not well controlled.

On the same time, the used of OPC as the main binder in construction material has been questioned over the last decades due to environmental problem during the manufacturing process. The production of OPC lead to CO_2 emission and also depletion of natural source materials. Hence, due to the issues which is against the perspective of sustainable development in the construction industry, an alternative solution was required.