A Review on Recycling Ash Derived from *Elaeis guineensis* By-product

Zhong Xian Ooi,[a] Hanafi Ismail,[a,]* Azhar Abu Bakar,[a] and Yi Peng Teoh [b]

Oil palm (*Elaeis guineensis*) ash is defined as the waste generated after the combustion of oil palm biomass. Malaysia is one of the world's largest producers and exporter of palm oil in the world, and there is approximately 4 million tonnes of oil palm ash generated annually. It is estimated that the amount of oil palm ash will keep increasing due to the high demand for palm oil globally. Normally, oil palm ash is disposed without any beneficial economic return value. The awareness of this environmental crisis has increased significantly over the past few years. With the evolution of ash utilization strategies, interest in oil palm ash in various research fields has grown. Through the effort of researchers and information available, the properties of the resulting materials are affected by the percentage of substitution and particle size of the oil palm ash. The major challenges in utilizing oil palm ash are discussed in this paper, as are the beneficial effects, which can include reducing the negative environmental impact and the product cost. Although the recycling of oil palm ash is still a new focus of interest, the main thrust of waste management in Malaysia will continue to focus on this kind of research and will attempt to solve the problem of disposal of the ash as well.

Keywords: Oil palm ash; Recycling; Environmental impact; Waste management

*Contact information: a: Division of Polymer Engineering, School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia, Engineering Campus, 14300 Nibong Tebal, Penang, Malaysia; b: Faculty of Engineering Technology, Universiti Malaysia Perlis, P.O. Box 77 d/a Pejabat Pos Besar, 01000 Kangar, Perlis; *Corresponding author: ihanafi@usm.my*

INTRODUCTION

Oil palm, *Elaeis guineensis* (Zeven 1964), is a tropical palm tree that is easily cultivated in tropical countries such as Malaysia and its neighboring countries. The origin of the oil palm has not yet been determined with certainty; it may have either a West African or South American origin. This information dates back to its long history. Several researchers claimed that the oil palm originated from South America (Cook 1942; Barry 1957); however, according to Zeven (1964), the widespread occurrence of oil palm happened in West and tropical Africa in the fifteenth and early sixteenth century and was recorded by the travelers at the time. The oil palm was then introduced from Africa into America concurrently with the slave trade. Because of the increase in demand, Europe began to invest in oil palm production, and the oil palm then expanded to Southeast Asia. Basiron (2007) reported that the first oil palm was taken to Malaysia and planted in 1875. This was the same time in which the rubber seed tree was brought into Malaysia. However, the first commercial planting in Malaysia was set up in 1917, located at the Tennamaran Estate in Kuala Selangor (Basiron 2007; Jagoe 1952).

Development of Malaysia's Oil Palm Industry

There are many ancient and traditional uses of oil palm trees, such as for clothing, timber for building, and for making baskets, mats, brooms, ropes, and fishing nets. The palm nut also could be a supply of food (Sarbah 1909).

In Malaysia, oil palm cultivation began in 1917, but the initial rate of expansion was slow. Oil palm trees were initially planted as an ornament plant and for landscaping or decorative purposes in gardens. During that time (when Malaysia was known as British Malaya), the government focused on promoting rubber seed planting, which generated greater value than the oil palm; consequently, fewer local people participated in oil palm production (Rahman 1998). According to Basiron and Weng (2004), the most rapid increase happened during the 1930s, 1970s, and 1980s, as shown in Table 1.

Table 1. Planted Area of the Oil Palm Agricultural Crop (Basiron and Weng 2004; MPOB 2013)

Years	Hectares	% Growth
<1910	<350	-
1920	400	14.2
1930	20600	5050.0
1940	31400	52.4
1950	38800	23.5
1960	54638	40.8
1970	261199	378.0
1980	1023306	291.8
1990	2029464	98.3
2000	3376664	66.3
2012	5076929	50.4

In the 1960s, the government was the driving force behind the expansion of oil palm plantations. The government encouraged and supported diversification in the agricultural sector to avoid dependence on rubber seed. This gave way to oil palm plantations, and soon most of the plantation companies had a mix of both crops (rubber and oil palm) as their core business. Malaysia became the leading oil palm exporter and replaced Nigeria completely (Panapanaan *et al.* 2009). After the 1970s, the oil palm expanded to Eastern Malaysia (*i.e.*, Sabah and Sarawak) (Rahman 1998). Oil palm trees have remained planted and can still be found in the area of the Universiti Sains Malaysia engineering campus today, as shown in Fig. 1. This shows the importance of oil palm production in Malaysia.

Apart from the plantations, the oil palm processing sector is well-established, comprising mills, refineries, oleochemical plants, and crushing factories. The oil palm industry has grown phenomenally over the past few decades to become a very important agricultural-based industry, which contributes to the socio-economic growth of Malaysia. Malaysia is well known for its oil palm plantations and currently is one of the world's largest producers and exporters of palm oil. Malaysia exports more than 90% of its palm oil and is also seeking new business areas (Teoh 2010). Malaysia not only focuses on palm oil and kernel processing, but also has given consideration to its biomass.

Fig. 1. Oil palm plantation at Universiti Sains Malaysia engineering campus

Oil Palm Biomass

According to Zwart (2013), the current production of crude palm oil is 19 million metric tonnes, and it is responsible for about 8% of the gross national income of Malaysia. Despite the obvious benefits, oil palm cultivation also contributes to some environmental problems. For example, oil palm estates produce a dry weight biomass; Malaysia's oil palm industries have generated an average of 53 million tonnes of residues every year (Umar *et al.* 2014). Rahman *et al.* (2014) reported that every 1 kg of palm oil produced would yield approximately 4 kg of dry oil palm biomass. In the year 2010, 80 million tonnes of dry oil palm biomass was produced. This amount is anticipated to rise annually and estimated will be risen to 100 million dry tonnes of solid biomass by the year 2020 (Rahman *et al.* 2014; Umar *et al.*, 2014) due to the expansion of crop plantations because of the high global demand for palm oil.

Apart from biomass from plantations, the palm oil processing plants also produce waste, as shown in Fig. 2. This waste can be produced in large quantities as well. Oil palm biomass includes the empty fruit bunches, kernel shells, fronds, and trunks. These are natural by-products and are non-toxic. Their respective compositions are listed in Table 2.

Table 2. Types of Oil Palm Biomass and their Respective Compositions in Weight Percent (Shibata *et al.* 2008; Tong and Hamzah 1989)

	Cellulose	Hemicellulose	Lignin	Extractives	Ash
Oil palm trunk	30.6	33.2	28.5	3.6	4.1
Oil palm frond	39.5	29.8	23.3	1.7	5.7
Palm kernel cake	35.7	30.3	15.7	11.7	6.7
Empty fruit bunch	37.9	35.0	24.0	2.7	1.5
Pressed pericarp fibers	39.9	28.9	20.3	-	3.6

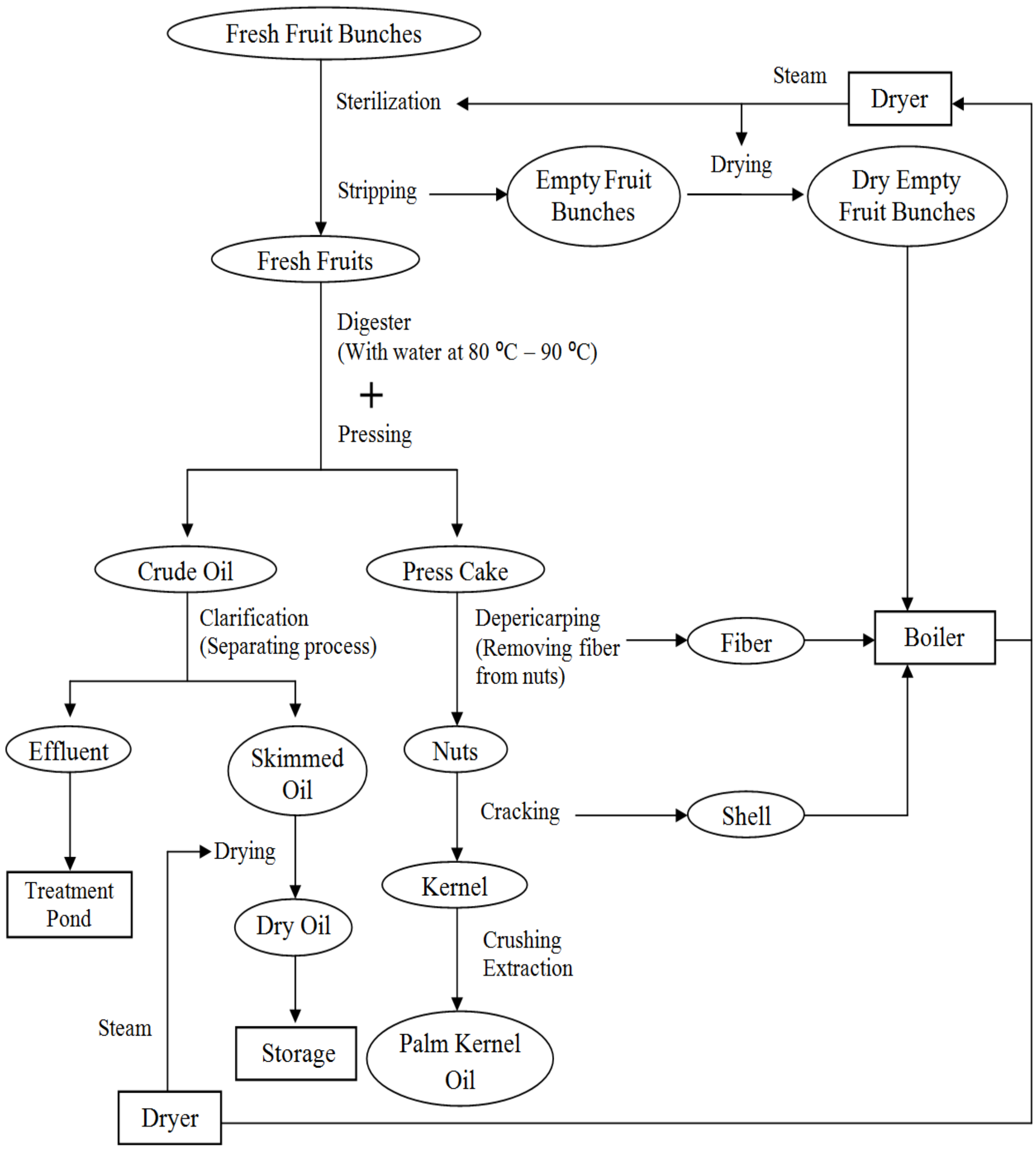

Fig. 2. Flow chart for processing in oil palm industries. Figure modified from Abdullah and Sulaiman (2013).

In the beginning, the non-utilized oil palm biomass created serious disposal problems when it was unscrupulously disposed. The cost of transportation and limited availability of landfills caused disposal of the oil palm biomass to become very expensive. In Malaysia, the transportation cost for the waste disposal reached as high as RM 66.10 (Negeri Sembilan) to RM 230.11 (Perlis) per metric ton (Mida 2014); thus, biomass was subjected to open burning to minimize the solid waste disposal sites. However, this action was discouraged by the Environment Department of Malaysia because open burning causes air pollution. Therefore, parts of the biomass are collected at palm oil processing plants and utilized by either direct combustion in a steam turbine system, pyrolysis, gasification, fermentation, or an anaerobic digestion method. The by-product is then converted into alternative fuel for energy and other bio-based products to meet the increasing demand for energy (Sridhar and AdeOluwa 2009; Abdullah and Sulaiman 2013).

Currently, palm oil processing plants use oil palm biomass, rather than palm oil, as a fuel for steam generation. This can help to reduce the use of fossil fuels. Weeraratne *et al*. (2007) reported that energy generation from the combustion of oil palm fiber and oil palm shell is sufficient to provide the energy required for a palm oil processing plant that uses 750 kWh of energy. Moreover, Malaysia's government has stated that oil palm biomass has the potential to become a primary source of energy. According to Jaafar *et al*. (2003), the renewable energy from oil palm biomass contributes about RM 6379 million in energy value *per annum*; thus, energy efficiency efforts have become the subject of much interest in recent years. Even though this effort could attract a huge investment, in the process of energy generation, a by-product is produced, *i.e.*, oil palm ash (OPA). The ash is produced in large quantities and normally illegally dumped in open fields or disposed of in landfills. OPA can cause severe environmental pollution if not correctly dealt with.

PHYSICOCHEMICAL CHARACTERIZATION OF OPA

Four million tonnes of OPA are produced annually in Malaysia, and it has been forecast that ash production will generally increase and vary directly with the increase in global demand of palm oil (Mohamed *et al*. 2005). Also, oil palm biomass is potentially available as a combustible material for self-generating energy in terms of steam and electricity in palm oil processing plants. Because of the large amounts of OPA obtained, there is much more investigation to be done to fully optimize the utilization of OPA in Malaysia instead of disposing of it in the landfill or illegally dumping it in an open field. According to studies done by Jaturapitakkul *et al.* (2007) and Yin *et al.* (2008), the surface of OPA particles is porous and spongy, which can be observed from the micrographs of OPA shown in Fig. 3; its physicochemical characteristics are listed in Table 3. The other elements (~90%) presented in OPA may be attributed to the presence of inorganic elements such as silicon (Si), potassium (K), calcium (Ca), aluminium (Al), magnesium (Mg), and phosphorus (P), *etc*.

As a note of caution, lead can be released from the OPA through the soils, water, and air, and thus contribute to environmental pollution if the OPA is disposed without proper handling. The lead, if present, would transfer to plants directly or indirectly. A high degree of lead accumulation (1 to 2 ppm) could stunt growth or even kill the plants by reducing the photosynthesis rate, inhibiting respiration, and thus consequently affecting the population genetics (The Lead Group Inc. 2014). Besides, lead hazards continue to pose a threat to health of living creatures such as damage to the eyes, hyperactivity, aggressive behavior, learning disabilities, developmental delays, and in rare circumstances coma and even death (DEQ 2014).

On the other hand, nickel is naturally occurring in the environment at low levels (0.2 ppm) as an essential element in some animal species and human nutrition. However, large exposures of nickel would negatively affect the environment and human beings. For example, high nickel concentration could damage the plants and also could stunt the algae growth. Respiratory effects had also been reported in humans from inhalation exposure to nickel (EPA 2013).

Based on the data tabulated in Table 3, the leachate pH of 10.8 was slightly higher as compared to the limiting values (6 to 9) provided by Malaysian Environmental Quality Act 1974 (MDC Sdn. Bhd. 1997). Thus, resolving or recycling of the OPA solid waste has attracted awareness by the Malaysia government. However, according to the toxicity characteristics leaching procedure (TCLP) method 1311 (USEPA 1998), Yin *et al*. (2008) showed that OPA is not a toxic waste, as there is no significant amount of heavy metal leaching. Thus, it has reasonable technical practicability, indicating the suitability of reuse as an alternative to its disposal.

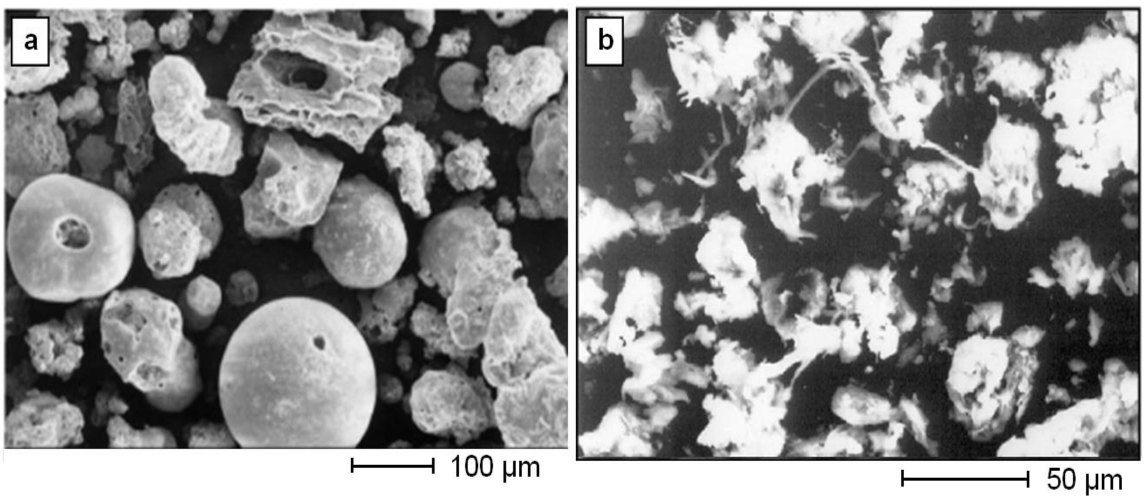

Fig. 3. Scanning electron micrographs of raw OPA. Fig. 1a, Jaturapitakkul *et al.* (2007) (*Construction and Building Materials*, 21(7), 1399-1405. Jaturapitakkul, C., Kiattikomol, K., Tangchirapat, W., and Saeting, T. “Evaluation of the sulfate resistance of concrete containing palm oil fuel ash”) and Fig. 1b, Yin *et al.* (2008) (*Fuel Processing Technology*, 89(7), 693-696. Yin, C. Y., Kadir, S. A. S. A., Lim, Y. P., Syed-Ariffin, S. N., and Zamzuri, Z. “An investigation into physicochemical characteristics of ash produced from combustion of oil palm biomass waste in a boiler”) reprinted with permission of Elsevier

Table 3. Physicochemical Characteristics of OPA at Segamat Oil Palm Mill (Yin *et al.* 2008)

Elemental analysis	
Carbon (wt%)	7.93
Hydrogen (wt%)	1.47
Nitrogen (wt%)	0.05
Other (wt%)	90.55
Loss-on-ignition analysis	
Organic content (wt%)	14.25
Toxicity characteristic leaching procedure (TCLP) analysis	
Copper (mg/L)	0.09
Cadmium (mg/L)	Not detected
Lead (mg/L)	0.12
Nickel (mg/L)	0.09
Leachate pH	10.80

RECYCLING OF OPA

Because OPA is available in large quantities at no cost/very low cost, various studies have been conducted in Malaysia and Thailand; they indicated that the utilization of OPA would be useful if it were transformed into value-added products or incorporated into original products. These findings offer many advantages with respect to environmental management. In the meantime, huge amounts of oil palm ash that will be discarded in landfill can be reduced. In addition, the utilization of low cost industrial agricultural waste could lead to a reduction in production costs.

Bio-Fertilizer from OPA

Based on the report done by Haron *et al.* (2008), a mixture of OPA and decanter cake (both are wastes supplied by Synn Palm Oil Mill, Taiping), can be utilized as a nutrient source for bio-compound fertilizer. Potassium is one of minerals required for plant growth. The fact that OPA contains a high percentage of potassium has led to the idea to mix it with decanter cake (contains high amount of nitrogen) as a palm-based bio-fertilizer. In their research work it was shown that this mixture can be further enriched by adding inorganic fertilizers in accordance with the Malaysian Palm Oil Board (MPOB) formulation. As a result, the palm-based bio-fertilizer contained high carbon (28%) and had a pH of 7 (Table 4), which would improve the soil inorganic matter content and reduce the acidity. Besides, Haron *et al.* (2008) also compared the nutrients uptake by oil palm seedlings by using the palm-based bio-fertilizer, standard inorganic compound fertilizer, and a control (without fertilizer), as tabulated in Table 5. The results indicated that the palm-based bio-fertilizer served as an effective fertilizer in supplying balanced nutrient levels (high N, P, and K; low Ca and Mg) to the plants. In addition, the growth of the oil palm seedlings with palm-based bio-fertilizer was significantly better (Table 5),

Table 4. Nutrient Contents and pH of OPA, Decanter Cake, and Palm-based Bio-fertilizer (Haron *et al*. 2008)

	N (%)	P_2O_5 (%)	K_2O (%)	CaO (%)	MgO (%)	C (%)	pH
OPA	0.14	2.78	21.1	3.85	1.26	-	12.82
Decanter cake	2.42	0.51	1.24	1.68	0.54	-	4.8
Palm-based bio-fertilizer	6.0	6.0	11.0	13.5	3.5	28.0	7.0

Table 5. Nutrient Concentration and Vegetative Growth of Oil Palm Seedlings with Different Treatments (Haron *et al*. 2008)

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Frond Length (cm)	Leaves area (m^2)	Frond dry weight (kg)
Palm-based bio-fertilizer	2.80	0.178	2.02	0.52	0.30	62.03	0.25	0.30
Standard inorganic fertilizers	3.09	0.172	1.86	0.34	0.31	53.42	0.18	0.28
Control	1.78	0.149	1.59	0.62	0.40	28.85	0.06	0.25

suggesting the slow release of organic material from bio-fertilizer and its high organic C compound would increase the nutrient uptake efficiency. Thus, mixing OPA and decanter cake with a small amount of inorganic fertilizer not only can produce cheaper bio-fertilizer, but also can reduce the solid waste disposal problem, as well as reduce the cost of oil palm plantation.

Fabrication of Cement Bricks from OPA for Construction

Another avenue of recycling research involves the investigation of utilizing OPA as a partial substitution in Portland cement. Based on the studies of Tangchirapat *et al*. (2009), OPA (supplied from an oil palm mill in Southern Malaysia) with high fineness can be used as a cement replacement; the compressive strength after substitution with 10% to 30% OPA in Portland cement was comparable to that of ordinary Portland cement (OPC). After 28 days, the compressive strength of concrete containing OPA increased and exhibited a higher value than that of OPC concrete. The silica that is contained in OPA could react with the $Ca(OH)_2$ in cement to form additional calcium silicate hydrate and enhance the interfacial bonding between the aggregates and pastes. Similar trends in compressive strength after substituting OPA have been observed by several researchers, as summarized in Table 6. Abdullah and Hussin (2010) also demonstrated that OPA has good fire resistance ability and a very low ability to spread the flame; thus, it can be classified as a non-combustible material.

Table 6. Compressive Strength of OPC Cement and Cement with the Addition of Various Concentrations of OPA

Mixed cement	Compressive strength (MPa)			References
	7 days	28 days	90 days	
OPC	54.9	58.5	64.7	Tangchirapat *et al*. (2009)
10 wt % ashes + OPC	55.6	59.5	67.5	
20 wt % ashes + OPC	54.6	60.9	69.4	
30 wt % ashes + OPC	53.2	58.8	66.1	
OPC	43.5	57.0	60.0	Chindaprasirt *et al*. (2008)
20 wt % ashes + OPC	43.5	57.5	62.0	
40 wt % ashes + OPC	32.5	53.5	61.5	
OPC	44.0	58.0	62.0	Rukzon and Chindaprasirt (2009)
10 wt % ashes + OPC	46.0	60.2	63.7	
20 wt % ashes + OPC	45.5	60.5	64.5	
40 wt % ashes + OPC	34.0	57.5	63.0	
OPC	68.8	77.5	87.5	Sata *et al*. (2004)
10 wt % ashes + OPC	71.7	81.3	89.1	
20 wt % ashes + OPC	71.1	85.9	91.5	
30 wt % ashes + OPC	68.5	79.8	88.7	

OPA as Absorbent for Gas Desulphurization and Wastewater Treatment

In addition to construction and building materials, OPA can also be used as an absorbent for sulfur dioxide (Mohamed *et al*. 2005; Zainudin *et al*. 2005) and/or to disperse dye (Ahmad *et al*. 2007; Hameed *et al*. 2007; Isa *et al*. 2007). Poisonous gas, such as sulfur dioxide, is produced from combustion of liquid and solid fuel, and the sulfur dioxide must be removed before being released into the environment, as it is considered toxic to humans by inhalation. Based on the research study done by Zainudin *et al*. (2005), OPA slurry mixed with calcium oxide and calcium sulfate demonstrated 100% removal of sulfur dioxide. When the absorbents derived from OPA were subjected to 500 ppm of sulfur dioxide, 5% O_2, 12% CO_2, and the balance N_2 at 30% relative humidity (RH) and a reaction temperature of 100 ºC, the sulfur dioxide was 100% removed during the first 26 min of the reaction. The absorption capacity at 90% sulfur dioxide removal was found to be 79 mmol of sulfur dioxide absorbed/g absorbent at a sulfur dioxide concentration of 2000 ppm.

Oil palm ash (collected from a local oil palm mill in Penang) also has been successfully used as an adsorbent material for removing color dyes (such as disperse blue, disperse red, and acid green 25 dye) from aqueous solution (Hameed *et al*. 2007; Isa *et al*. 2007). However, the absorption capacity was found to be affected by the solution’s pH; lower pH favored absorption activity. Hasan *et al*. (2008) confirmed that chitosan/OPA composite beads can be excellent absorbents when removing reactive blue 19 dye from aqueous solution.

OPA as Filler in Rubber, Thermoplastic Elastomer, and Plastic Manufacturing

The primary aim of OPA utilization in polymers is to reduce the cost of polymer compounds and mitigate the environmental crisis caused by the amount of OPA produced. The effects of the incorporation of OPA (supplied by United Oil Palm Mill, Penang) from 10 phr to 40 phr in the rubber matrix were studied (Ismail and Haw 2008), and it was found that the utilization of OPA caused a reduction in properties such as tensile strength, elongation at break, fatigue life, and rubber-filler interaction. The reason for this may be attributed to the agglomeration of hydrophilic ash, causing poor adhesion of OPA to the natural rubber matrix. This was revealed by a scanning electron microscope (SEM) image, as shown in Fig. 4. However, the scorch and cure time could be shortened, particularly at higher ash loading. The utilization of OPA in ethylene vinyl acetate/natural rubber blends was investigated by Najib *et al*. (2009), who noted that the incorporation of OPA (10 to 40 phr) reduced the tensile strength and elongation at break values of ethylene vinyl acetate/natural rubber blends as agglomeration took place. Thus, non-uniform stress transfer and restriction of molecular chain flexibility occurred. At the same time, the research findings indicated that composites with smaller OPA particle sizes exhibited higher tensile strength and elongation at break than those with larger particle sizes. This hypothesis was further validated by the SEM images shown in Fig. 5, showing that more uniform palm ashes and less agglomeration was observed in the ethylene vinyl acetate/natural rubber/OPA composites when smaller particle sizes were added.

Because of the reduction in tensile strength, much research has been carried out concerning hybrid fillers such as OPA/silica (Ismail and Haw 2010) and OPA/halloysite nanotubes (Ismail and Shaari 2010) in natural rubber and ethylene-propylene-diene monomers, respectively. Hybrid fillers combine the physical properties of the individual constituents. During this experiment, OPA exhibited a beneficial effect by decreasing the cure rate of rubber composites.

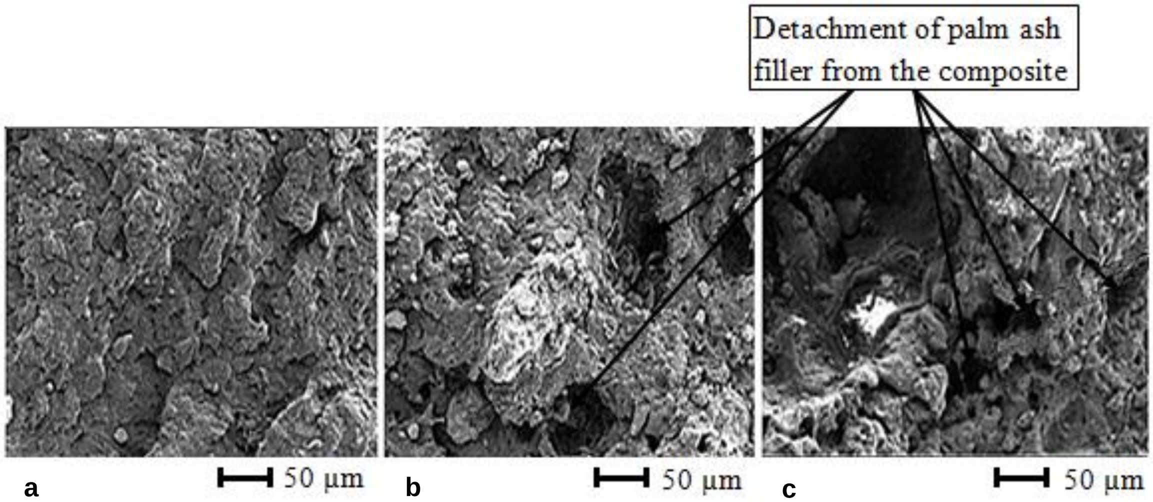

Fig. 4. SEM images of tensile fractured surfaces of OPA-filled natural rubber composites with varying compositions: (a) 0 phr; (b) 10 phr; and (c) 30 phr. Figures from Ismail and Haw (2008) (*Journal of Applied Polymer Science*, 110(5), 2867-2876. Ismail, H. and Haw, F. S. "Effects of palm ash loading and maleated natural rubber as a coupling agent on the properties of palm ash filled natural rubber composites") reprinted with permission from John Wiley & Sons

Bhat and Khalil (2011) explored the utilization of OPA (collected from Segamat Oil Palm Mill) in polypropylene composites. The incorporation of OPA (1 to 7%) increased the tensile and impact strengths as compared to the polypropylene alone. This was attributable to the lack of agglomeration at low OPA loadings and the favorable interfacial properties.

In recent years, studies have investigated the utilization of OPA (supplied by United Oil Palm Mill, Penang) in natural rubber composites at low filler loadings (Ooi *et al*. 2013a). OPA has also been compared to commercial fillers such as silica and carbon black (Ooi *et al*. 2013b). The tensile strength and elongation at break of natural rubber composites were improved by 16% and 7.4%, respectively, at 1 phr loading of OPA. From a reinforcement point of view, composites with 1 phr of OPA showed comparable strength to composites with 50 phr carbon black while retaining the elongation at break of natural rubber composites.

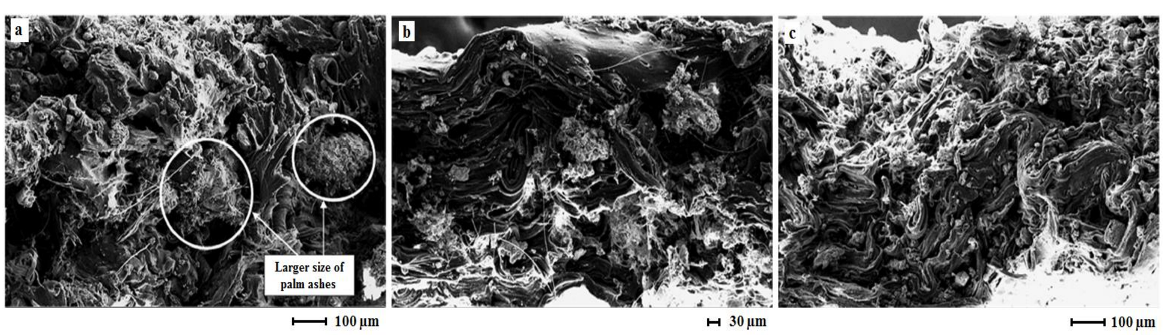

Fig. 5. SEM images of tensile fractured surfaces for varying sieve sizes of (a) 500 micron, (b) 150 micron, and (c) 75 micron OPA-filled ethylene vinyl acetate/natural rubber blends. Figures from Najib *et al*. (2009) (*Polymer-Plastics Technology and Engineering*, 48(10), 1062-1069. Najib, N. N., Ismail, H., and Azura, A. R. "Thermoplastic elastomer composites of palm ash-filled ethylene vinyl acetate/natural rubber blends: Effects of palm ash loading and size") reprinted with permission from Taylor & Francis LLC

MAJOR CHALLENGES

Prior to utilization of OPA, which is considered an industrial agricultural waste, there is an aspect that still needs to be considered. According to Foo and Hameed (2009), OPA from different oil palm mills shows various chemical constituents (such as silicon oxide, calcium oxide, aluminum oxide, and magnesium oxide). It is clear that the mineralogical compositions of the ash depend on geographical conditions, fertilizers used, soil chemistry, and agronomic practices in the oil palm growth process. Pushparajah (1994) also reported that the nutrient level in the plant tissues is affected by many factors, not only the inherent soil factors, but also modifying factors such as the fertilizers used and the age of the crop. The type of oil palm biomass that is combusted is one of the factors that affects the chemical constituents of OPA because the nutrient uptake different parts of oil palm trees is not the same. It is fitting to say that the mineralogical composition of OPA will vary even if it is collected from the same oil palm mill at different times. The chemical constituents that are contained in OPA (Mohamed *et al*. 2005; Ismail and Haw 2008; Ooi *et al*. 2013c) from United Oil Palm Mill at different times are listed in Table 7. This phenomenon may be attributed to the nutrient uptake for the optimal growth of oil palm trees and the types of oil palm biomass taken for combustion because it may vary from time to time. Therefore, the utilization of OPA as a partial substitution and/or filler may affect the certain properties of the products, especially the rubber cure rate, which is also affected by the metal oxide content. To minimize the variation, the types of oil palm biomass have to be selected and classified prior to combustion for generating energy.

Table 7. Chemical Constituents of OPA Collected from United Oil Palm Mill, Penang, Malaysia

Constituents	Compositions (%)		
	Mohamed *et al*. (2005)	Ismail and Haw (2008)	Ooi *et al*. (2013c)
Silicon dioxide (SiO_2)	35.6	10.0	34.0
Aluminum oxide (Al_2O_3)	4.8	0.8	3.9
Iron oxide (Fe_2O_3)	2.0	0.3	1.9
Calcium oxide (CaO)	12.0	3.4	7.3
Magnesium oxide (MgO)	7.2	3.0	3.8
Sodium oxide (Na_2O)	-	0.1	0.1
Potassium oxide (K_2O)	6.8	27.0	3.7
Sulfur trioxide (SO_3)	-	1.8	0.4
Phosphorus oxide (P_2O_5)	6.8	2.4	3.2

Moreover, the OPA particles observed are irregular in shape, which may lead to voids within the filler and the matrix. Also, the size of OPA could cause another difficulty in polymer processing because the particle size of collected OPA varies. Larger particles may create stress concentration points and in turn reduce the strength of the composites. This problem can be solved by separating larger particles from smaller ones.

CONCLUSIONS

1. Forecasts for the next 6 years indicate an increasing impact of agricultural waste production, including oil palm residues in Malaysia. The biomass amount is estimated to rise to 100 million dry tonnes of solids by the year 2020; therefore the awareness of resolving oil palm ash (OPA) waste disposal problem becomes a serious issue of concern for the Malaysian government.
2. The OPA can be used to produce cheaper bio-fertilizer that is as effective as other fertilizers available on the market. Besides, OPA shows potential utilization in a wide range of applications such as an adsorbent for gas desulphurization and wastewater treatment, cement bricks, rubber, and plastic manufacturing.
3. Additional research studies and innovation can still be conducted to expand the utilization of OPA in numerous fields due to the increasing negative impact of OPA disposal on the environment.
4. Even though the applications of OPA are still not commercialized and are mostly in the research stage, extensive advances in OPA utilization can be expected in the future.

ACKNOWLEDGEMENT

This work was financially supported by the Ministry of Science, Technology and Innovation (MOSTI) science fund (Project no. 305/PBAHAN/6013380), and MyPhD (Z. X. Ooi).

REFERENCES CITED

Abdullah, K., and Hussin, M. (2010). "Fire resistance properties of palm oil fuel ash cement based aerated concrete," *Concrete Res. Lett.* 1(3), 107-114.

Abdullah, N., and Sulaiman, F. (2013). "The oil palm wastes in Malaysia," (http://cdn.intechopen.com/pdfs/44387/InTech-The_oil_palm_wastes_in_malaysia.pdf). Accessed 23 October 2013.

Ahmad, A. A., Hameed, B. H., and Aziz, N. (2007). "Adsorption of direct dye on palm ash: Kinetic and equilibrium modelling," *J. Hazard. Mater.* 141(1), 70-76.

Barry, D. (1957). "The African relative of the Chilean wine palm," *Principles* 2, 180-182.

Basiron, Y. (2007). "Palm oil production through sustainable plantations," *Eur. J. Lipid Sci. Technol.* 109(4), 289-295.

Basiron, Y., and Weng, C. K. (2004). "The oil palm and its sustainability," *J. Oil Palm Res.* 16(1), 1-10.

Bhat, A. H., and Khalil, H. A. (2011). "Exploring "Nano Filler" based on oil palm ash in polypropylene composites," *BioResources* 6(2), 1288-1297.

Chindaprasirt, P., Rukzon, S., and Sirivivatnanon, V. (2008). "Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash," *Constr. Build. Mater.* 22(5), 932-938.

Cook, O. (1942). "A Brazilian origin for the commercial oil palm," *The Scientific Monthly* 54(6), 577-580.
DEQ (2014). "Environmental Lead, Department of Environmental Quality," (http://www.michigan.gov/deq/0,4561,7-135-3307_29693_30031---,00.html). Accessed 05 August 2014.
EPA (2013). "Nickel Hazard Summary, United States Environmental Protection Agency," (http://www.epa.gov/ttn/atw/hlthef/nickel.html). Accessed 05 August 2014.
Foo, K. Y., and Hameed, B. H. (2009). "Value-added utilization of oil palm ash: A superior recycling of the industrial agricultural waste," *J. Hazard. Mater.* 172(2-3), 523-531.
Hameed, B. H., Ahmad, A. A., and Aziz, N. (2007). "Isotherms, kinetics and thermodynamics of acid dye adsorption on activated palm ash," *Chem. Eng. J.* 133(1), 195-203.
Haron, K., Mohammed, A. T., Halim, R. M., and Din, A. K. (2008). "Palm-based bio-fertilizer from decanter cake and boiler ash of palm oil mill," *Information Series (MPOB TT No. 412)*, 1-4.
Hasan, M., Ahmad, A. L., and Hameed, B. H. (2008). "Adsorption of reactive dye onto cross-linked chitosan/oil palm ash composite beads," *Chem. Eng. J.* 136(2), 164-172.
Isa, M. H., Lang, L. S., Asaari, F.A. H., Aziz, H.A., Ramli, N. A., and Dhas, J. P. A. (2007). "Low cost removal of disperse dyes from aqueous solution using palm ash," *Dyes Pigments* 74(2), 446-453.
Ismail, H., and Haw, F. S. (2010). "Curing characteristics and mechanical properties of hybrid palm ash/silica/natural rubber composites," *J. Reinf. Plast. Comp.* 29(1), 105-111.
Ismail, H., and Haw, F. S. (2008). "Effects of palm ash loading and maleated natural rubber as a coupling agent on the properties of palm ash filled natural rubber composites," *J. Appl. Polym. Sci.* 110(5), 2867-2876.
Ismail, H., and Shaari, S. M. (2010). "Curing characteristics, tensile properties and morphology of palm ash/halloysite nanotubes/ethylene-propylene-diene monomer (EPDM) hybrid composites," *Polym. Test.* 29(7), 872-878.
Jaafar, M. Z., Kheng, W. H., and Kamaruddin, N. (2003). "Greener energy solutions for a sustainable future: Issues and challenges for Malaysia," *Energy Policy* 31(11), 1061-1072.
Jagoe, R. B. (1952). "Deli oil palms and early introductions of *Elaeis guineensis* to Malaya," *Malaya Agric. J.* 35(1), 4-11.
Jaturapitakkul, C., Kiattikomol, K., Tangchirapat, W., and Saeting, T. (2007). "Evaluation of the sulfate resistance of concrete containing palm oil fuel ash," *Constr. Build. Mater.* 21(7), 1399-1405.
MDC Sdn. Bhd. (1997). Laws of Malaysia - Environmental Quality Act 1974 and Regulation. 4th Edn., Kuala Lumpur, Malaysia.
MIDA (2014). "Scheduled waste treatment rates, Malaysian Investment Development Authority," (http://www.mida.gov.my/env3/index.php?page=scheduled-waste-treatment-rates). Accessed 11 March 2014.
MPOB (2013). "Economics & Industry Development Division, Malaysia Palm Oil Board," (http://bepi.mpob.gov.my/images/area/2012/Area_summary.pdf). Accessed 24 September 2013.

Mohamed, A. R., Lee, K. T., Noor, N. M., and Zainudin, N. F. (2005). "Oil palm ash/Ca $(OH)_2/CaSO_4$ absorbent for flue gas desulfurization," *Chem. Eng. Technol.* 28(8), 939-945.

Najib, N. N., Ismail, H., and Azura, A. R. (2009). "Thermoplastic elastomer composites of palm ash-filled ethylene vinyl acetate/natural rubber blends: Effects of palm ash loading and size," *Polym. Plast. Technol. Eng.* 48(10), 1062-1069.

Ooi, Z. X., Ismail, H., and Abu Bakar, A. (2013a). "Synergistic effect of oil palm ash filled natural rubber compound at low filler loading," *Polym. Test.* 32(1), 38-44.

Ooi, Z. X., Ismail, H., and Abu Bakar, A. (2013b). "Optimisation of oil palm ash as reinforcement in natural rubber vulcanisation: A comparison between silica and carbon black fillers," *Polym. Test.* 32(4), 625-630.

Ooi, Z. X., Ismail, H., and Abu Bakar, A. (2013c) "Characterization of oil palm ash (OPA) and thermal properties of OPA filled natural rubber compounds," *J. Elastom. Plast.* E-pub ahead of publication.

Panapanaan, V., Helin, T., Kujanpää, M., Soukka, R., Heinimö, J., and Linnanen, L. (2009). *Sustainability of Palm Oil Production and Opportunities for Finnish Technology and Know-How Transfer*, Research Report/Lappeenranta University of Technology, Faculty of Technology, LUT Energy, Finland.

Pushparajah, E. (1994). "Leaf analysis and soil testing for plantation tree crops," (http://www.agnet.org/htmlarea_file/library/20110804160807/eb398.pdf). Accessed 12 March 2014.

Rahman, A. A. A. (1998). "Malaysian Oil Palm Industry. Retrospect and Prospect, Paper presented at 1998 International Oil Palm Conference, Indonesia," (http://tpu.upm.edu.my/~salbiah/production.html). Accessed 28 September 2013.

Rahman, M. E., Boon, A. L., Muntohar, A. S., Hashem Tanim, M. N., and Pakrashi, V. (2014). "Performance of masonry blocks incorporating palm oil fuel ash," *Journal of Cleaner Production* 78(1), 195-201.

Rukzon, S., and Chindaprasirt, P. (2009). "Strength and chloride resistance of blended Portland cement mortar containing palm oil fuel ash and fly ash," *Int. J. Min. Met. Mater.* 16(4), 475-481.

Sarbah, J. M. (1909). "The oil-palm and its uses," *J. Royal Afr. Soc.* 8(31), 232-250.

Sata, V., Jaturapitakkul, C., and Kiattikomol, K. (2004). "Utilization of palm oil fuel ash in high-strength concrete," *J. Mater. Civil Eng.* 16(6), 623-628.

Shibata, M., Varman, M., Miyafuji, Y. T. H., and Saka, S. (2008). "Characterization in chemical composition of the oil palm (*Elaeis guineensis*)," *J. Japan Ins. Energy* 87(5), 383-388.

Sridhar, M. K. C., and AdeOluwa, O. O. (2009). "Palm oil industry residues," in: *Biotechnology for Agro-Industrial Residues Utilisation*, P. Nigam and A. Pandey (eds.), Springer, the Netherlands.

Tangchirapat, W., Jaturapitakkul, C., and Chindaprasirt, P. (2009). "Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete," *Constr. Build. Mater.* 23(7), 2641-2646.

Teoh, C. H. (2010). *Key Sustainability Issues in the Palm Oil Sector, International Finance Corporation (IFC)*, Discussion Paper for Multi-Stakeholders Consultations (commissioned by the World Bank Group).

The Lead Group Inc. (2014). "Effects of lead on the environment," (http://www.lead.org.au/lanv1n2/lanv1n2-8.html). Accessed 05 August 2014.

Tong, C. C., and Hamzah, N. M. (1989). "Delignification pretreatment of palm-press fibres by chemical method," *Pertanika* 12, 399-403.
Umar, M. S., Jennings, P., and Urmee, T. (2014). "Sustainable electricity generation from oil palm biomass wastes in Malaysia: An industry survey," *Energy* 67, 496-505.
United States Environmental Protection Agency (USEPA) (1998). *Method 1311. Toxicity Characteristic Leaching Procedure, SW-846: Test Methods for Evaluating Solid Waste*, Physical/Chemical Methods.
Weeraratne, J., Surif, S., and Yusof, S. (2007). "Application of industrial ecological system by applying life analysis: A case study in a palm oil mill," *3rd International Conference on Life Cycle Management*, Zurich.
Yin, C. Y., Kadir, S. A. S. A., Lim, Y. P., Syed-Ariffin, S. N., and Zamzuri, Z. (2008). "An investigation into physicochemical characteristics of ash produced from combustion of oil palm biomass waste in a boiler," *Fuel Process. Technol.* 89(7), 693-696.
Zainudin, N. F., Lee, K. T., Kamaruddin, A. H., Bhatia, S., and Mohamed, A. R. (2005). "Study of adsorbent prepared from oil palm ash (OPA) for flue gas desulfurization," *Sep. Purif. Technol.* 45(1), 50-60.
Zeven, A. C. (1964). "On the origin of the oil palm (*Elaeis guineensis* Jacq.)," *Grana Palynologica* 5(1), 121-123.
Zwart, R. (2013). "Opportunities and challenges in the development of a viable Malaysian palm oil biomass industry," *J. Oil Palm Environm.* 4(2013), 41-46.

Article submitted: March 21, 2014; Peer review completed: July 19, 2014; Revised version received: August 6, 2014; Accepted: August 7, 2014; Published: September 9, 2014.