Suitability and Characteristics of Combustion Residues from Renewable Power Plants for Subbase Aggregate Materials, in Thailand

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Physico-chemical properties and the environmental impacts were studied relative to the leaching of rubber fly ash and bottom ash. The pozzolanic properties of fly ash and bottom ash were confirmed by the chemical composition, including silicon oxides, calcium oxides, and aluminum oxides. The geo-technical characteristics of rubber wood fly ash and bottom ash, *i.e.*, modified compaction, plasticity, and the soaked California Bearing Ratio, were evaluated to assess the feasibility of fly ash or bottom ash mixed with lateritic soil as aggregate materials for the subbase in road construction in order to optimize the replacement of lateritic soil by fly ash or bottom ash. The leachates from rubber fly ash and bottom ash did not exceed standard thresholds. The measured characteristics of fly ash or bottom ash mixed with lateritic soil were in good alignment with the effective engineering thresholds. Recommendations were developed for safe reuse of byproducts from rubber renewable power plant in subbase road construction.

Keywords: Renewable power plant; Rubber wood; Incineration residues; Construction materials; Leaching test; Road construction

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INTRODUCTION

Biomass power plants are an alternative pathway to reclaim a large quantity of agricultural wastes to produce electricity and to achieve the objectives of the Alternative Energy Development Plan (AEDP) in Thailand (Prasertsan and Sajjakulnukit 2006; Sutabutr 2012). However, a large expansion of biomass power plants to support the government policies has increased the wastes produced from electricity production, including fly ash (FA) and bottom ash (BA) (Sutcu *et al.* 2019). FA and BA are porous, solid by-products from the complete or incomplete combustion of biomass. The ash byproducts contain carbon and oxides of calcium, silicon, and aluminium matters, and their characteristics vary by temperature and conditions in the furnace (Dahl *et al.* 2009; Vamvuka and Kakaras 2011; Phoungthong *et al.* 2016b; Agrela *et al.* 2019). FA and BA are regarded as particularly hazardous and costly to dispose, requiring a large area for landfill use (Hjelmar 1996; Phoungthong *et al.* 2016a). There are many reports about the reuse of FA and BA as environmentally friendly and low-cost materials in various applications as adsorbents, for soil amendment, or as aggregate materials for structural concrete or road construction (Mukhtar *et al.* 2003; Skousen *et al.* 2013; Orakwue *et al.* 2016; Rafieizonooz *et al.* 2016; Lynn *et al.* 2017; Zhou *et al.* 2019). Therefore, the growing demand for environmentally friendly and sustainable materials is expected to propel the growth of the construction industry (Bheel *et al.* 2018). Currently, the utilization of FA and BA in road construction is of great concern, because the properties of FA and BA are similar to natural materials, such as pozzolan, which can be used as an additive for cement materials in construction or as binder in road construction (Jaturapitakkul and Cheerarot 2003; Marinkovic *et al.* 2006). There is prior research on the utilization of FA and BA in road construction. For example, François and Criado (2007) reported on utilizing the FA from power plants as the aggregate material for road construction. Izquierdo *et al.* (2008) showed that BA mixed in as the aggregate material can be used in the concrete pavement layer in road construction. The development of rubberwood biomass power plants to generate electricity is an interesting renewable energy alternative in Thailand; the cumulative amount reaches 25 million trees per year. This is one of the main fuels in use in Southern Thailand, at approximately 800 tons of rubber wood per day, which produce approximately 16 tons of ash per day with approximately 80% fly ash and approximately 20% bottom ash (Gulf Yala Green Company 2016). Due to the large amount of FA and BA residues produced from renewable power plants, the reuse of FA and BA waste as cost-effective and eco-friendly components in road construction is an alternative way to dispose of waste or, ideally, to reuse and/or recover waste. In this work, the FA and BA were obtained from a renewable power plant using para rubber wood residues as fuel. However, the FA and BA contain silicon dioxide (SiO_2), calcium oxide (CaO), and heavy metals (As, Ba, Cu, Cd, Pb, Zn, *etc.*); therefore, the physico-chemical characteristics of FA and BA were studied. The relevant and useful information on basic characteristics can be generated and may help to assess the risks that possibly result from the utilization of these ashes as aggregate materials in road construction (Phoungthong *et al.* 2018; Itam *et al.* 2019).

Lateritic soil is a suitable natural aggregate for such use as the main ingredient in the subbase layers of road pavement. As a result of the growth demand for construction materials, there have been large increases in the volume of lateritic soils that were employed for road pavement. While demand for the material had risen, construction companies were finding it more difficult to properly manage their supplies of lateritic soil, especially in the Southern region of Thailand where only 12.23% of lateritic soil deposit is found (Chantruthai *et al.* 2017). An alternating way is to optimize the volume of lateritic soil and mix it with FA or BA as FA- or BA-lateritic soil bound forms as aggregate materials. The possible application of rubber-wood-based FA and BA is particularly of interest in Southern Thailand where there are problems related to expansive soils, an abundance of biomass power plants, and an increased amount of rubber tree biomass waste.

The purpose of the present work was to evaluate the possibility of using FA and BA in lateritic soil treatment to stabilize and to prevent erosion from falling rain (*i.e.*, pumping) as an aggregate material in the subbase of roads, according to the standard technical specifications for subbase road works regulated by the Department of Highways in Thailand. A further goal was to advance the sustainable use of rubber wood FA and BA in lateritic soil bound forms.

The characteristics of FA and BA are dealt with first, covering the physico-chemical and engineering properties, followed by an examination of their mechanical and durability performances. The physico-chemical properties, such as specific gravity, moisture content, loss on ignition (LOI), and environmental impact of FA and BA as aggregate material, including their chemical compositions and leaching characteristics, were studied. In addition, engineering properties, such as the modified compaction test (MCT), comparative measure of the shear strength with California Bearing Ratio (CBR), and plasticity testing, were assessed.

EXPERIMENTAL

Materials

The lateritic soil was obtained from Southern Thailand. The grain size range in the lateritic soil was around 0.01 to 1.2 mm. Rubber wood FA and BA samples were collected from the renewable power plants of Gulf Yala Green Company in Southern Thailand. All ash samples were collected directly during full operation of the boilers and therefore, complete combustion under ideal conditions can be assumed. FA and BA were used as received in this experiment. Anupam *et al.* (2013) reported that "the chemical, physical and engineering properties of ashes depend on the type and source of biomass used, method and degree of biomass preparation, cleaning and pulverization, type and operation of power generation unit, ash collection, handling and storage methods *etc.* Therefore, the properties of fly ash vary from plant to plant and even within the same plant." Thus, it is important to investigate the physical and chemical properties of rubber wood FA and BA obtained in the current study. In this current work, an optimization of the ratio of FA bound lateritic soil and BA bound lateritic soil was performed, and the individual ash and lateritic soil were blended with 2% of water to obtain 5 kg of aggregate material in the ratios 15%, 30%, 45%, and 60% for FA and 15%, 30%, 45%, 60%, 80%, and 100% for BA in the mechanical testing experiments.

Test Standards

Physico-chemical properties of FA and BA

The specific gravity was determined according to standard ASTM C188-14 (2014), by measuring the gas displacement volume obtained using the Le Chatelier flask method. True density was determined using a gas displacement pycnometer AccuPyc II 1340 (Micromeritics Instrument Co., Norcross, GA, USA). The standard value, according to ASTM C32-13 (2017) is in the range 2.20 to 2.80. For particle size determinations, 325 sieves were used according to ASTM C618-12 (2012), and the particle sizes of FA and BA were tested using a laser particle size analyzer, (LS 230; Beckman Coulter, Brea, CA, USA). The density of FA and BA was investigated using the gas displacement method with the true density analyzer (AccuPyc II 1340; Micomeritics, Norcross, GA, USA). Loss on ignition (LOI) of the FA and BA, according to ASTM D7348-13 (2013), was determined. A 5 g sample of FA or BA was placed in a crucible and was then heated at 0 to 200 °C for 30 mins, and continued heating to 600 °C for 3 h. The crucible was cooled to room temperature. Vandenberghe *et al.* (2010) reports that the % LOI should be less than 6%. The % LOI was calculated using Eq. 1,

$$\%\ \mathrm{LOI} = \left(\frac{W_2 - W_3}{W_2 - W_1}\right) \times 100 \quad (1)$$

where W_1 represents the mass of empty crucible (g), W_2 represents the total mass (g) of crucible and ash (FA or BA) before heat treatment, and W_3 represents the total mass (g) of crucible and ash (FA or BA) after heating to 600 °C.

The crystalline structure of the rubber wood FA and BA was screened with an X-ray diffractometer (XRD) (X'Pert MPD; Philips, Malvern, UK). The chemical components in FA and BA were determined using an X-ray fluorescence (XRF) spectrometer (PW2400; Philips, Malvern, UK). The various elements (*i.e.*, As, B, Ba, Be, Bi, Cd, Co, Cr, Cu, Mn, Ni, Pb, Se, Sr, V, and Zn) were screened using this technique. The environmental impacts of the utilization of FA and BA as the aggregate material were studied in leaching tests. The Toxicity Characteristic Leaching Procedure (TCLP) and the Synthetic Precipitation Leaching Procedure (SPLP) were used to investigate the metal ions in the leachate water. The TCLP (0.1 mol/L, pH = 2.88 ± 0.05) was used as leaching water to simulate the leaching of landfill, and the SPLP (H_2SO_4/HNO_3 (60:40 w/w) solution (pH = 4.20 ± 0.05)) was used in the leaching to simulate acid rain conditions. For physico-chemical property studies, all experiments were repeated three times, and the statistical analysis was performed with SPSS Version 21.0 statistic software.

Engineering experiments

The plasticity indices were determined to establish the limited moisture range in which the material remains in a plastic state. The standards DH-T103/1972 (1972) and ASTM D4318-00 (2000) were used. The modified compaction test (MCT) is a laboratory geotechnical testing method used to determine aggregate materials compaction properties as well as to determine the optimum water content in which the aggregates can reach their maximum dry density. The MCT was tested according to the standard DH-T 108/1974 (1974) corresponding with the standard ASTM D1557-07 (2007). The compaction was tested at 25 °C with the given water content in a standard mold with a standard compaction energy. The sealed curing for the premature samples in a mold, diameter size was 10 cm, proceeded for 7 days at 25 °C. The procedure specifies a hammer weighing 4.537 kg and a fall distance of 457.2 mm. The CBR tests of FA and BA were completed following the standard DH-T 109/1974 (1974) (corresponding with ASTM D1883-05 (2005)) with the samples used in the subbase layer in road construction. The CBR test indicates the ratio of force per unit area required to penetrate a mixture mass with standard circular piston at the rate of 1.25 mm/min to that required for the corresponding penetration of a standard material. The CBR test was conducted in 4-day soaked conditions, and the soaked CBR value compared to standard should be more than 25%. The properties of the subbase mixtures of FA- or BA-lateritic soil containing 15%, 30%, 40%, and 60% by weight of FA or 15%, 30%, 40%, 60%, 80%, and 100% by weight of BA were studied in this work. All engineering experiments were repeated three times, and the statistical analysis was performed with SPSS Version 21.0 statistic software.

RESULTS AND DISCUSSION

Physico-chemical Properties of FA and BA

The physical properties of FA and BA, including specific gravity, density, average particle size, and LOI are shown in Table 1. The specific gravities of FA and BA were 2.26 and 2.12, respectively, which were in the standard specific gravity range of 2.20 to 2.80 for subbase aggregate material, from ASTM C188-14 (2014). The particle size of FA ranged from 0.4 to 786.9 μm with an average particle size of 72.9 μm, and the particle size range of BA was 0.40 to 1818 μm with an average particle size of 695 μm. The specific gravities of FA (2.26) and BA (2.12) were similar, but the average particle sizes differed strongly because the FA contained many particles with a cavity inside, *i.e.*, cenospheres or plerospheres. These microspheres were caused by the combustion of floating ash due to small, trapped air bubbles inside, and contain small mineral particles, foam, or other porous framework. Therefore, the particle sizes of FA varied from small (*i.e.*, a few microns) to several hundred microns; additionally, the specific gravity of FA varied and might be dramatically heavier than usual (Fenelonov *et al.* 2010). The LOI tests provided a measure of the organic fraction by comparing the difference in mass before and after ignition. The basic engineering properties of FA and BA in various respects were studied. Residual organic matter remaining in FA and BA after the combustion can potentially lead to negative impacts on density and stiffness and an increased risk of degradation by ignition (Arm 2000). The LOI of FA was 19.20%, which was above the standard recommendation (≤ 6%, as per ASTM D7348-13 (2013)) (Bhatt *et al.* 2019). An increase in LOI reduced the quality of the FA by high carbon content, which limited its applicability in concrete due to remarkable air-entrainment, affecting the durability of concrete (Blissett and Rowson 2012); in addition, the water demand consistently increased, resulting in a lower compressive strength of the concrete (Vandenberghe *et al.* 2010; Mohebbi *et al.* 2015). Therefore, the use of FA with lateritic soil (low LOI of 0.53 as reported by Spain *et al.* (1982)) in stabilized mixture is required to improve the properties of concrete for subbase layer use in road construction. Even though the average particle size of BA was larger than that of FA, its LOI of 1.77% complied with the standard (≤ 6%), matching the ash properties reported by Hawa *et al.* (2013).

Table 1. General Properties of Fly Ash and Bottom Ash

Parameter	Fly Ash	Bottom Ash
Specific gravity (g/cm^3)	2.259	2.122
Density (g/cm^3)	2.255	2.118
Average particle size (μm)	72.88	694.90
LOI (%)	19.20	1.77

Table 2 shows the chemical compositions of FA and BA from XRF determinations compared with the oil palm frond ash (Nnochiri and Aderinlewo 2016) and rice husk ash (Sani *et al.* 2020), which were reported in using with lateritic soil in geotechnical properties. The FA had high contents of K_2O (43.18%), CaO (18.54%), and SiO_2 (0.88%), while BA had high contents of SiO_2 (41.20%), followed by CaO (26.93%) and K_2O (9.89%). The percentages of CaO of FA and BA can be compared with the percentage of CaO in oil palm frond ash (28.66%), matching the report by Chen *et al.* (2014), which indicated that material with a high content of CaO could be used as aggregate in cement. In addition, because the SiO_2 content of BA is higher than that of FA, BA is more suitable to use for road construction corresponding the high content of SiO_2 observed in rich husk ash.

In addition, the pozzolanic reactivity in cement hydration was increased by a high CaO content (Setina *et al.* 2013). Phoungthong *et al.* (2018) reported that coal-fly ash has a high content of CaO (the chemical composition can vary depending on the type of biomass and the combustion temperature).

Table 2. Inorganic Components in Fly Ash and Bottom Ash

Inorganic Component	FA (%)	BA (%)	Oil palm frond ash (%)[a]	Rice husk ash (%)[b]
SiO_2	0.88	41.20	33.67	74.75
CaO	18.54	26.93	28.66	3.22
Al_2O_3	0.33	2.62	14.79	-
K_2O	43.18	9.89	3.41	6.78
Fe_2O_3	0.23	2.89	4.51	2.25
SO_3	12.27	0.60	-	-
P_2O_5	2.25	2.37	3.99	9.45
MgO	3.49	3.13	3.97	-
TiO_2	-	0.24	-	0.17
MnO	0.54	0.56	-	1.35
Rb_2O	0.33	0.06	-	-
SrO	0.09	0.09	-	-
ZrO_2	-	0.04	-	0.022
Cl	0.73	-	-	-
Na_2O	-	-	0.52	1.3
V_2O_5	-	-	-	0.10
CuO	-	-	-	0.035
ZnO	-	-	0.89	0.176
SiO_3			5.59	-

[a] Oil palm frond ash (Nnochiri and Aderinlewo, 2016) and [b] Rice husk ash (Sani *et al.* 2020) used with lateritic soil for the geotechnical properties

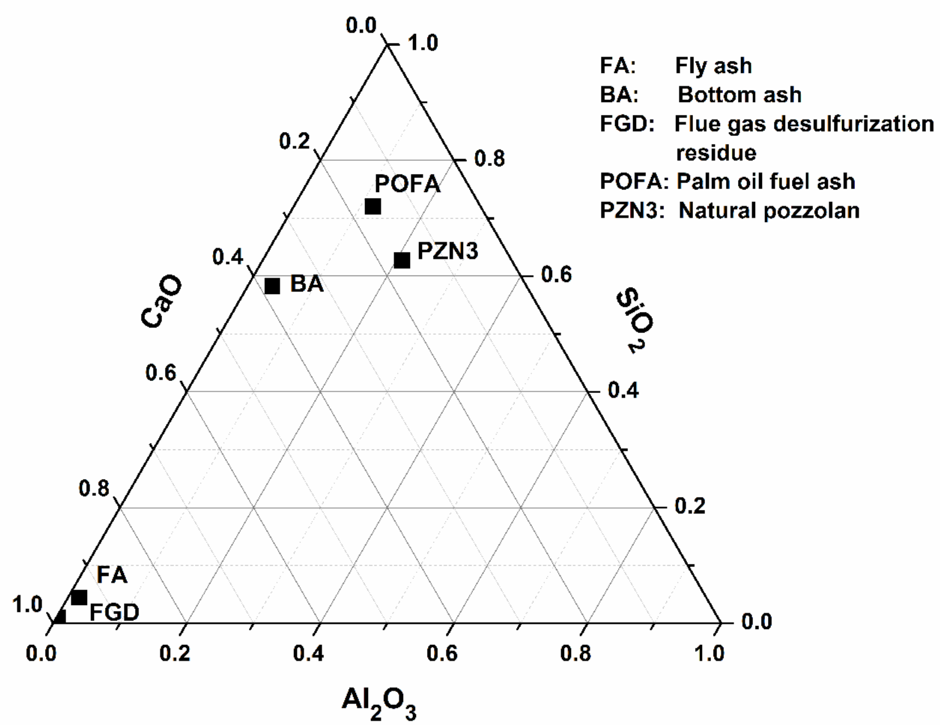

Fig. 1. The CaO-SiO_2-Al_2O_3 ternary phase diagram for FA and BA, along with other previously reported pozzolanic materials including FGD, POFA, and PZN3

The ternary phase $CaO-SiO_2-Al_2O_3$ diagrams for FA and BA (Fig. 1) were analogous to the pozzolanic materials (*i.e.*, flue gas desulfurization residues (FGD), palm oil fuel ash (POFA), and natural pozzolan (PZN3)) used in construction engineering applications (Meulenyzer *et al.* 2013; Chen *et al.* 2014; Demis *et al.* 2014). In comparison, the aggregate materials that appear at the bottom left of the triangle were rich in CaO. The compositions were comparable to those of previous studies, with materials obtained from various sources in China (Hua *et al.* 2010; Chen *et al.* 2014). The aggregate materials that appear at the top of the triangle were rich in SiO_2, which is a pozzolanic material (Meulenyzer *et al.* 2013; Demis *et al.* 2014). Therefore, the FA and BA had the main chemical components of pozzolanic materials and could be used as aggregate material in road construction concrete.

The minerals in crystalline phases of FA and BA are shown by the XRD patterns in Fig. 2. The peaks for FA show a predominance of $K_2(SO_4)$, $K_2Ca(CO_3)_2$, $Ca(CO_3)$, MgO, $Ca_5(PO_4)_3Cl$, and $MgCO_3$, while the BA had predominantly SiO_2 and $Ca(CO_3)$ (Hua *et al.* 2010; Chen *et al.* 2014). However, the mineral compositions of rubber wood FA and BA were influenced by the biomass origin (*i.e.*, para rubber wood) and the combustion conditions, resulting in different XRD patterns (Ruangtaweep *et al.* 2011; Phoungthong *et al.* 2018).

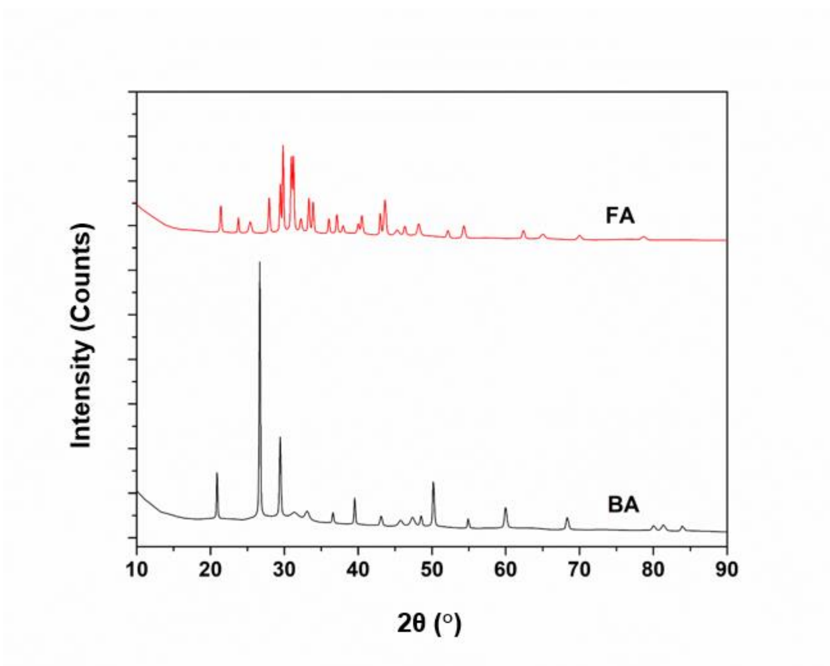

Fig. 2. XRD spectra of FA and BA

Additionally, the inorganic contents in FA and BA were investigated with the inductively couple plasma-optical emission spectrometry (ICP-OES) technique and were compared to the soil quality standards issued by the Ministry of Natural Resources and Environment in Thailand (Table 3). The low toxicity components Cu and Zn were observed in the FA at slightly higher levels than in standards for soil quality. The heavy metals Pb, Cd, and Hg were detected in the FA, while only Pb was detected in the BA, but only at acceptable levels as issued by the Ministry of Natural Resources and Environment in Thailand. Therefore, to investigate the environmental impacts of using FA and BA in road construction, leaching tests of FA and BA were conducted.

Table 3. Inorganic Metal Ion Contents in Fly Ash and Bottom Ash

Inorganic Metal Ions	FA (g/kg)	BA (g/kg)	Soil Quality (g/kg)
Cu	0.12	0.04	< 0.03
Mn	2.52	1.85	< 32
Zn	0.97	0.09	< 0.15
Pb	0.11	0.005	< 0.75
As	< LOD *	< LOD	< 0.30
Ba	0.43	0.36	-
Cd	0.01	< LOD	< 0.81
Cr	0.03	0.03	< 0.64
Se	< 0.009	< LOD	≤ 10
Ni	0.04	0.03	≤ 41
Hg	<0.0002	< LOD	≤ 0.61
B	0.11	< LOD	-
Co	< 0.0007	0.002	-
V	0.002	0.03	-

*Limits of detection (LOD) determined by ICP-OES technique

The leaching tests by both TCLP and SPLP methods for FA and BA materials were performed with analyses by the ICP-OES technique. The FA leachates from TCLP and SPLP methods had pH in the ranges 10.1 to 11.35 and 9.31 to 12.51, respectively, while the BA leachates by TCLP and SPLP had pH in the ranges 7.14 to 7.32 and 10.00 to 10.38, respectively. The leachate pH levels indicated a high indicating alkalinity. The heavy metal ion leaching rate tends to be lower in more alkaline conditions (François and Criado 2007; Spence and Forsha 2012; Yin *et al.* 2018). The leaching tests of FA and BA by 0.1 M acetic acid (CH_3COOH) and by H_2SO_4/HNO_3 at L/S 20 were conducted to simulate leaching from a landfill by acid rain. Table 4 shows that the leaching of metal ions from FA and BA in both TCLP and SPLP methods were below the threshold concentration issued by the Department of Industrial Works in Thailand.

Table 4. Total Threshold Limit Concentration (TTLC) and Soluble Threshold Limit Concentration (STLC) Tests for Leaching Water from Fly Ash and Bottom Ash

Metal Ions	FA (mg/L)		BA (mg/L)		STLC (mg/L)
	TCLP	SPLP	TCLP	SPLP	
B	3.522 ± 0.0292	6.136 ± 0.0828	< LOD	< LOD	-
Ba	0.008 ± 0.0002	0.036 ± 0.0004	1.312 ± 0.0150	0.074 ± 0.0030	100.0
Cd	< 0.001	0.004 ± 0.0002	< LOD	< LOD	1.0
Cr	0.696 ± 0.0050	0.692 ± 0.0124	<0.002	0.018 ± 0.0004	5.0
Co	< LOD **	< LOD	< 0.002	< LOD	80
Cu	0.002 ± 0.0002	0.010 ± 0.0002	0.012 ± 0.0010	0.080 ± 0.008	25
Pb	< LOD	<0.007	< LOD	< 0.011	5.0
Zn	< 0.001	0.010 ± 0.0006	< LOD	0.042 ± 0.0006	250

Engineering properties of FA and BA

To assess the engineering properties of FA and BA for feasible use in the subbase layer in road construction, the MCT, the plasticity index (PI), and the CBR were investigated (Table 5). The MCT is used in geotechnical engineering to evaluate the compaction behavior in terms of maximum dry unit weight and optimum water content (Cabrera *et al.* 2014; Mohammadinia *et al.* 2017; Cabrera *et al.* 2018). Compaction characteristics of the FA and BA were measured and analyzed for varied ratios of an individual ash to lateritic soil. It was found that 15% to 60% of FA and 15% to 100% of BA aggregates blended with lateritic soil had the optimum moisture contents in the ranges 96.4 to 103 and 97.9 to 107 complying with the standard ASTM D1558-99 (1999) (> 95). Therefore, adding FA or BA improved the workability of FA- or BA-lateritic soil blends as aggregate materials in subbase road construction, which reduces the need for water for compaction (Cabrera *et al.* 2014, 2018). The plasticity indices were determined to establish the limited moisture range in which the material remains in a plastic state, which determines whether an aggregate material is non-plastic, by evaluating the response of the material to variations in moisture content (Batari *et al.* 2017; Cabrera *et al.* 2018). The plasticities of FA and BA were less than 11% according to the standard ASTM D4318-00 (2000), except when the aggregate material had 45% of BA (% PI 12.9). Table 5 also shows the results obtained from soaked CBR tests for FA or BA mixed with lateritic soil. The soaked CBR values of FA-lateritic soil aggregates were less than the standard value (> 25) for subbase road construction, while the soaked CBR values of BA-lateritic soil aggregates at 15%, 30%, 45%, 60%, 80%, and 100% were 87.3%, 101.4%, 117.4%, 159.4%, 118.3%, and 37.9%, respectively. Therefore, all BA-lateritic soil mixtures improved the soil bearing capacity. In addition, an increase in CBR values resulted in increasing BA content, with the optimum value being 60% BA content. This increase could be due to an adequate amount of calcium required for the formation of calcium silicate hydrate and calcium aluminate hydrate, which are the major compounds responsible for strength gain (Doneliene *et al.* 2016). The soaked CBR values were consistent with previous reports on biomass ashes, such as olive biomass bottom ash and rice husk ash, as additives for construction materials, in which the soaked CBR value first increased with the content of ash, but at excessive contents of ash, the soaked CBR decreased (Basha *et al.* 2005; Cabrera *et al.* 2018). This is related to the highly pozzolanic properties of BA due to its chemical composition, allowing BA to serve as a stabilizing material in road construction (Shvarzman *et al.* 2002; Bose 2012). Therefore, adding 60% BA in aggregate material to reduce the use of lateritic soil decreases the water absorption and makes it suitable for subbase application with the highest MCT value and low plasticity. This replacement increases the strength property of subbase aggregate material with the highest CBR value.

Table 5. Mechanical Testing of FA and BA Blends with Lateritic Soil

Parameter	FA Content (%)				BA Content (%)						Standard Value
	15%	30%	45%	60%	15%	30%	45%	60%	80%	100%	
MCT (%)	102.1	96.4	100.0	103.4	105.7	103.6	103.8	107.0	98.42	97.87	> 95
PI (%)	5.5	7.6	5.8	7.8	9.5	4.8	12.9	6.2	6.75	6.21	< 11
Soaked CBR (%)	8.7	18.4	18.7	8.3	87.3	101.4	117.4	159.4	118.3	37.9	> 25

Implications

In Thailand, the rapid increase of electrical power production is causing concerns regarding the management of biomass-fired power plants (using rubber tree as biomass). This is due to the power shortages and delays in the power supply from the transmission distribution networks. At present, Thailand endeavors to replace natural gas and oil with biomass as fuel in power plants because rubber trees are readily available at a comparatively low cost. According to the 2018 power plan, issued by the Electricity Generating Authority of Thailand, it is estimated that within the years 2018 to 2036, the electrical power demand in Thailand will increase from 30,218 MW to 49,655 MW, with a GDP increase of approximately 3.94% per year (Ministry of Energy of Thailand 2015). The rate of power demand growth will be 2.67% annually. To meet this demand of electricity requires 870 MW and 1,100 MW additional power generation capacity until 2021. For this reason, the Thai government has announced a policy to accelerate the development of the power supply network. The utilization of biomass (*e.g.*, rubber tree) fired power plants has been encouraged, although power plants have also been globally regarded as problematic to the environment. Although rubber wood FA and BA appear suitable for the applications examined, their leaching and engineering properties vary considerably depending on the biomass source. An assessment of environmental impacts and risks associated with biomass ash needs to be performed prior to the utilization of these materials.

CONCLUSIONS

1. The physico-chemical properties and environmental impacts as regards to leaching from rubber fly ash and bottom ash were studied. The specific gravities of FA and BA were similar, but the FA contained microspheres causing variation in its size distribution and in its specific gravity.
2. Loss on ignition tests were completed. The LOI for BA was near the specified standard value, while the LOI of FA exceeded the standard threshold. Such high LOI indicated poor quality of the FA due to excessive carbon content, which limits its applicability as an aggregate material due to remarkable air-entrainment, impacted durability, and increased water demand resulting in reduced compressive strength. Therefore, blending FA to a stabilized mixture with lateritic soil would be required for use in subbase road construction applications.
3. The pozzolanic properties of fly ash and bottom ash were confirmed by their chemical compositions containing silicon oxides, calcium oxides, and aluminum oxides. The low toxicity components Cu and Zn were observed in the FA at slightly higher levels than in standards for soil quality. The heavy metals Pb, Cd, and Hg were detected in the rubber wood FA, while only Pb was detected in the rubber wood BA, but only at acceptable levels as issued by the Ministry of Natural Resources and Environment in Thailand. Moreover, the metal concentrations of the leachates from rubber FA and BA did not exceed standard thresholds but remained acceptable for subbase road construction.
4. The geotechnical characteristics of rubber fly ash and bottom ash, including modified compaction, plasticity, and soaked CBR, were studied. The measured values were in good alignment with the established threshold values indicating that FA or BA mixed with lateritic soil can be used as an alternative material for subbase road construction. Additionally, the soaked CBR first increased with the ash content, but at excessive contents of FA and BA, it decreased. This was related to the highly pozzolanic properties of BA due to its chemical composition, allowing the BA to act as a stabilizing

material in road construction. Recommendations were suggested for sustainable reuse of rubber plant residues from renewable power plants in subbase road construction.

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