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UTILIZATION OF BOTTOM ASH FOR CLAY MINE REHABILITATION

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Abstract: At the end of mining activities, clay mines were abandoned due to the cost and non-availability of filling materials. These abandoned clay mines cause adverse environmental and social impacts. In addition, large quantities of bottom ash (BA) are generated as a by-product of coal combustion process. This BA is disposed by open dumping in the lands, which creates severe environmental pollution. Therefore, conducted research on utilization of BA for mine rehabilitation is beneficial. The main focus of this research is applicability of BA generated from Lakvijaya power plant, Sri Lanka as a potential backfill material and a soil amendment during the clay mine rehabilitation. Initially tests were conducted to investigate the basic properties of BA. Next, chemical composition of BA was analysed to select the suitable crops for vegetation. Further pH, electrical conductivity and water holding capacity were checked and micro structural morphology of BA was determined through Scanning Electron Microscope. The results showed that BA has good engineering properties and the potential to improve agronomic characteristics of soil. It has better water holding capacity and permeability. BA can adjust soil pH to a desirable plant growth range. As BA has a very porous structure, the root system can easily develop and helps to uptake nutrients by the plant. However, a considerable percentage of trace metals is accumulated in BA which will increase the bioavailability of some trace metals to levels that poses risk to human. Thus, investigations were carried out to identify the heavy metal concentration in leachate of BA using column leaching test. Results showed that leachability potential of trace metals in BA does not exceed the allowable limits.

Keywords: bottom ash; clay mines; compaction; soil amendment; trace metals

1. Introduction

1.1 General background

Clay mining is one of the land degrading methods. As a result of continuous clay mining, many topological changes tend to occur (Matsumoto *et.al.*, 2016). Most of the clay mining is continued along the river basins due to the availability of quality clay and the most fertile layers are removed due to mining. According to US Geological Survey Department's Mineral report on Sri Lanka, about 70,000 Mt of clay was mined in year 2014 (Renaud, 2018). As the demand for clay bricks and clay roof tiles increasing day by day, it is impossible to erect limitations on the extraction of clay. This has created many abandoned clay mines without any rehabilitation due to the higher cost and lack of suitable filling material. These abandoned clay mines have led to many adverse environmental and social effects such as increasing infectious diseases, soil erosion and slope stability (Ranasinghe, 1996). Hence, an adequate precaution should be taken as soon as possible for the rehabilitation of these abandoned clay pits.

1.2 Bottom ash (BA)

According to the study of World of Coal Ash (WOCA) the estimated generation of BA from coal thermal power plants in the world has been moved to an approximate amount of 730 Mt per annum (Singh *et.al.*, 2020). Based on the study of Gimhan *et.al.* (2018), Lakvijaya coal power plant in Norochcholai, Sri Lanka produces around 50,000 Mt of BA annually. The method used for the disposal of the BA is open dumping into lands which creates environmental issues such as air, water and soil pollution. Hence, new disposal techniques have to be found. Even though BA has shown the properties which suits for construction material in previous researches, still it is being dumped to the lands in large amounts as a waste. Therefore, conducted research on utilizing BA for clay mine rehabilitation will be very beneficial.

1.3 Properties of BA

BA is a granular, coarse and incombustible by product of coal. In general, the particles of BA have porous textures with angular and dark shapes. Generally, particle size of BA is between 0.1 – 10 mm and considered as a well-graded or poorly graded material based on unified soil classification system (Jayaranjan *et.al.*, 2014). These properties of BA depend on the type of burner, operation procedure of the power plant and quality and type of coal burned (Chrishanthi, 2019). In addition, BA exhibits low compressibility characteristics, high strength and higher permeability (Yuksel and Genc, 2007). BA exhibits relatively good engineering properties which makes BA as an ideal material for dam design and for other applications in civil engineering.

1.4 Utilization of BA for geotechnical applications

According to past studies, BA can be utilized in numerous ways such as coarse aggregates, fine aggregates, for cement production, highway material and etc. Apart from this BA is also used for some geotechnical engineering purposes such as a fill material, to prevent soil erosion, as a soil stabilizer, for geo polymer and soil amendment (Chrishanthi, 2019). BA is a well-drained material with lower bulk density and hence considered a good fill material (Kim and Lee, 2015). Kim *et.al.* (2005) have stated that BA can be used in projects like in highway embankment construction. With the application of BA and lime on soft soils, engineering properties such as strength and bearing capacity have been improved while decreasing compressibility characteristics (Gimhan *et.al.*, 2018).

According to Sivakumar *et.al.* (2015), stabilization of cohesive soil with BA showed better results when compared to cohesive soil without admixtures. As a geo polymer material, BA helps in controlling greenhouse gas emission by replacing cement mortar (Kim and Lee, 2015). The usage of BA in preventing soil erosion has been discussed by the study of Matsumoto *et.al.* (2016). The results show that the possibility of soil erosion can be reduced significantly by adding fly ash and bottom ash with a proportion of more than 85% of sand to top cover soil at the mixing ratio of over 30%. The high water retention capacity of BA due to the microporous structure helps in preventing the soil erosion.

1.5 BA as a soil amendment

According to Ranasinghe (1996), clay pits have an average total surface area ranging from 10 to 105 acres in different villages in Sri Lanka. Hence, restoration of clay mines with a vegetation cover would be more environmentally friendly and aesthetically pleasing. With the introduction of BA, soil properties can be altered in favour of the environment. BA has the chemical and physical properties which suits the soil in various agricultural applications. Soils mixed with BA have displayed acceptable pH value, electrical conductivity and high water holding which are in desirable for plant growth

(Wearing *et.al.*, 2008). Some soils require an addition of lime to preserve its pH value. And BA can be applied as an alternative for those soil. It may increase pH of the soil, improve soil structure, and water infiltration, which is appropriate for crop cultivation (Wearing *et.al.*, 2008). Further, BA contains many essential plant nutrients like, calcium (Ca), iron (Fe), Magnesium (Mg), potassium (K) and silicon (Si) (Wearing *et.al.,* 2008), which will eventually facilitate better growth of plants.

1.6 Problems related in using BA

However, some problems are associated with the continuously use of BA as a potential fill material. Due to the mechanized clay mining, large clay pits of about average depth of 8 - 24 feet are abandoned by the miners without rehabilitating them (Ranasinghe, 1996). When these clay pits are filled with BA, it may cause for ground water contamination. Chemical composition of BA is similar to fly ash however typically contain a higher carbon content (Kumar *et.al.*, 2012). The exact composition of the bottom ash might depend on the burner properties (type, size and the operating conditions of the burner) and the raw coal source (Jayaranjan *et.al.*, 2014). Generally, a significant percentage of Sodium (Na), Calcium (Ca), Magnesium (Mg), Pottassium (K) and heavy metals such as Arsenic (As), Boron (B), Cadmium (Cd), Chromium (Cr), Copper (Cu), Mercury (Hg), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Antimony (Sb), Selenium (Se), and Zinc (Zn) are accumulated in BA particles (Jones *et.al.*, 2012). Hence, there is a possibility of leaching these trace metals into soil, groundwater and surface water, when applying high rates of BA for backfilling. It will lead to the increased bioavailability of some trace metals to levels that poses risk to human and ecological health. This cause for negative public perception in the usage of BA due to the health risks associated with it and hence need to be studied prior to the application of BA in the field.

Therefore, the main objective of this research is to investigate the suitability of BA as a fill material for clay mine rehabilitation paying more attention to the suitability as a soil amendment. It is obtained by conducting appropriate laboratory experiments including particle size distribution, Scanning Electron Microscopy (SEM) analysis, specific gravity, Atterberg limit, Proctor compaction test, permeability test, pH, electrical conductivity, water holding capacity and heavy metal leachability tests.

2. Experimental methodology

BA generated from the Lakvijaya coal power plant, Sri Lanka was used for this study.

2.1 Investigate the basic properties of BA

Particle size distribution was done according to ASTM C-136. Modified Proctor compaction tests were conducted according to ASTM D 678. As BA is a highly porous material, 24 hours of saturation period as stated in the ASTM standards were not enough for testing. Hence after conducting several trial tests by standard and modified proctor test for different saturation periods, modified proctor test after one- week saturation period was selected as it gave the optimum results. The cone penetration test was used to determine the liquid limit. The plasticity test was not done for BA as it is considered as non-plastic by referring to the literature (Gimhan *et.al.*, 2018). Constant head test and specific gravity test was done according to ASTM D 2434-19 and ASTM D 854 respectively.

2.2 Conduct testing for BA as a soil amendment

Chemical composition of BA was analysed to select the suitable crops for vegetation. Further pH, electrical conductivity and water holding capacity of BA were checked. Electrical conductivity and pH were measured using digital meters. Water holding capacity was measured based on the retention percentage of water in BA. A filter paper was placed at the bottom of the funnel. Then, 50 g air-dried sample was placed in a funnel and 100 ml water was added. Sample was kept for 1-2 hours of time duration until there was no more visible drainage. After that, the weight of the saturated sample was measured, and sample was oven dried at 105 °C. The weight of the oven dried sample was measured and water holding capacity was calculated. The micro structural morphology of BA was determined through Scanning Electron Microscope (SEM).

2.3 Evaluate the trace metals leachability of BA

The column leaching test was conducted under saturation conditions. The column was made with Perspex. For testing, BA was filled up to 150mm and BA sample was compacted to its maximum dry density under optimum moisture content to represent field application. Bottom of the column was lined with geotextile to prevent particle loss. During the test, height of 100 mm constant head was maintained. The test was carried out for a period of 96 hours as used by Takao *et.al.* (2008). A schematic diagram of the experimental setup of column leaching test apparatus is shown in figure 1 (All dimensions are in mm). Collected leachate samples during the testing were analysed using inductively – coupled plasma mass spectrometry (ICP – MS) technique facility due to its lower detection limits (Chrishanthi, 2019, Takao *et.al*., 2008).

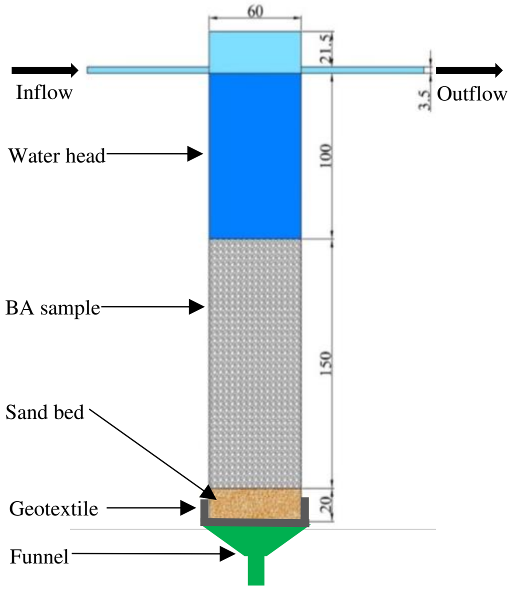


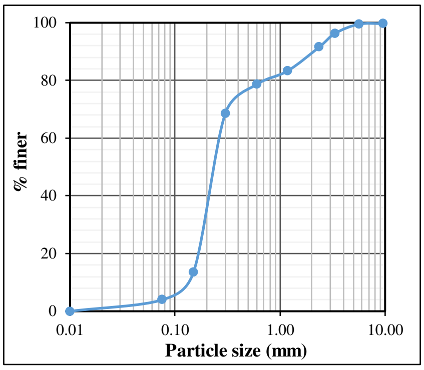
Figure 1: Schematic diagram of column leaching test set up

3. Results and Discussion

Following sections discuss the results obtained after laboratory tests for BA during the application as a fill material for clay mine rehabilitation.

3.1 Suitability of BA as a fill material

Particle size distribution curve and modified Proctor compaction curves of BA are presented in figure 2 and 3, consequently. And the basic properties of BA are illustrated in the table 1. BA used for the present study is classified as poorly graded sand (SP) and according to table 1, specific gravity of BA is much lower than that of a normal inorganic soil. Further, BA used for the present study has lower maximum dry density and a comparatively higher optimum moisture content like a soil with higher plasticity. However, during the compaction tests, BA samples mixed with water was non-plastic and workable at all used moisture contents. Figure 3 also shows that air voids lines lie below the compaction curve. All these observations lead to the indication that the BA has a porous structure. These pores are getting filled easily by the water added during the compaction, thus requiring more water fir the process of compaction. Later, this porous structure was confirmed through Scanning Electron Microscope (SEM) monographs and is shown in figure 4.



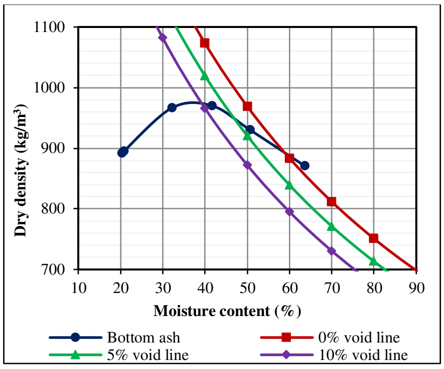


Figure 2: Particle size distribution curve of BA

Figure 3: Modified proctor compaction curve of BA

Table1: Properties of BA

Basic properties	**Values**
Soil Classification	Poorly Graded Sand - SP
Specific gravity	1.88
Liquid limit (%)	20
Maximum dry density (kg/m^3)	975
Optimum moisture content (%)	37
Coefficient of permeability (m/s)	9.9 x 10^{-5}
pH	8.2
Electrical conductivity (µS/mm)	702
Water holding capacity (%)	66

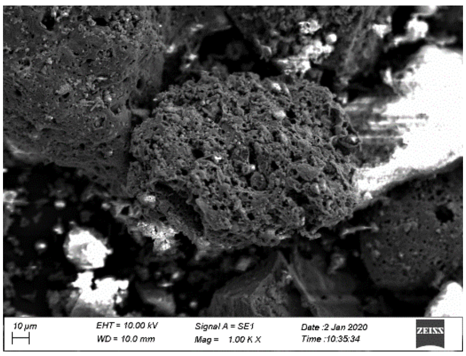


Figure 4: SEM monograph of BA

Microstructure of the tested BA samples shows freely available scattered popcorn like structure. BA particles exhibit irregular and rough surface texture and internal porous structure is clearly evident (average pore size is around 1.95 μm). These pores are getting filled easily by the moisture added during the compaction, thus requiring more water for the process of compaction. Even with the absorption of large amount of water into this porous structure, the bulk density of the compacted BA at the maximum dry density is still quite low (1336 kg/m^3) compared to conventional fill materials. Hence, BA can be considered as a lightweight fill material and beneficial for construction on soft grounds like the abandoned clay mining areas.

3.2 Suitability of BA as a soil amendment

Chemical composition of the BA sample is shown table 2. As witnessed by Wearing *et.al.* (2008), the useful plant nutrients can be observed in the BA obtained from Lakvijaya Power plant as well, such as Ca, Fe, and Si. BA is an alkaline soil with a pH value of 8.2. Most plant nutrients are available in 6.5 – 7 pH range and hence, BA can be used to improve the pH of slightly acidic soil and makes it suitable for agriculture. The soluble salt content of BA is 702 μS/mm which represents the moderately saline class based on soil salinity classifications.

Table 2: Chemical composition of BA

Chemical composition	**Values**
Aluminium Oxide (Al_2O_3) (%)	17.94
Calcium Oxide (CaO) (%)	1.85
Chloride content (Cl) (%)	0.097
Ferrous Oxide (Fe_2O_3) (%)	7.85
Silica (SiO_2) (%)	35.79
Sulfuric Anhydride (SO_3) (%)	0.04
Total Alkali content (Na_2O) (%)	0.37
Arsenic (As) (mg/kg)	0.5
Cadmium (Cd) (mg/kg)	Not detected
Chromium (Cr) (mg/kg)	0.9
Lead (Pb) (mg/kg)	Not detected
Mercury (Hg) (mg/kg)	Not detected

Further, the water holding capacity of BA is high (refer table 1). Therefore, the nutrients can retain in the soil and is good for plant growth. This higher water holding capacity reduces water losses as drainage, improving efficiency in water use and increasing crop yields. With the increase in water holding capacity, decrease in permeability can also be expected (Moreno *et.al*., 2005). However, higher permeability observed for BA (refer table 1) will mitigate this problem. The porous structure of BA will be further advantageous to develop the root systems of the plants well and for the solubility of nutrients and ability to uptake nutrients by the plant. Hence, utilizing BA as a soil amendment is favourable during clay mine rehabilitation.

3.3 Trace metals leachability of BA

The concentration of As, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn obtained from column leaching tests along with allowable limits as per drinking water for United States Environmental Protection Agency (USEPA) guidelines are summarised in table 3. When compared with the allowable limits, concentrations of selected trace metals were well below the regulatory values.

Table 3: Trace metals concentration after column leaching test of BA

Metal	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
Concentration (ppm)	-	-	0.017	0.023	-	0.012	0.008	-	0.034
Allowable Limits*(ppm)	0.01	0.005	0.1	1.3	0.002	0.02	0.015	0.05	5

*United States Environmental Protection Agency (USEPA) drinking water standards

3.4 Implications for field application

The physical, chemical and geotechnical properties of BA were favourable to be used as a fill material for clay mine rehabilitation. BA is a lightweight fill material which suits to fill the soft grounds like clay mines. This research will therefore help the clay miners to fulfil the regulations of rehabilitating the clay mines at a lower cost after mining. However, different mixtures of locally available soils with BA might improve the compaction properties (MDD and OMC) as per the need in the field application and should be tested. Further, some preliminary testing should be conducted to check the properties of BA prior to the application in the field as BA is a highly heterogeneous material.

BA has good soil texture, bulk density, water holding capacity and permeability when compared to soil. BA can buffer acidic soils and adjust soil pH to a range that optimizes the availability of most plant nutrients. Therefore, BA can perform as a soil amendment material economically, geologically, chemically and agronomically as stated in table 4.

Table 4: Comparison of BA and agricultural soil

Properties	Agricultural soil	BA soil amendment
pH	6.5 – 8 (Neina, 2019)	8.2
Electrical conductivity (µS/mm)	240 - 320 (cropaia, 2020)	702
Water holding capacity (%)	20.7 – 46.5 (Jayanthi, 2007)	66

BA used as a soil amendment will be a better way to mitigate the environmental and social impacts due to disposal of BA. In addition, these areas can be converted into recreational areas after re-storing with vegetation. With the help of environmental authority and the local governments, these restored quarries can be rehabilitated with native flora and fauna. Plants such as Blue Grama Grass (Boutelous gracilis), Buffalo Grass (Buchloe dactyloides) grow under tropical conditions and alkaline soils (De, 2017). Hence they can be grown using BA. Further, by adding acid forming materials, pH value of BA can be adjusted to suit other types of plants as well. This will restore the ecological balance and the aesthetics of the area while creating economical advantages for the locals.

4. Conclusions and Recommendations for future studies

Following sections list the conclusions of the research and recommendations for future studies.

4.1 Conclusions

According to the findings of the present study, BA has the following properties;

- lower specific gravity, lower bulk and dry density and therefore, can be considered as a lightweight fill material which is suitable to fill soft grounds like abandoned clay mines.
- higher water holding capacity, higher electrical conductivity and has necessary plant nutrients which increase crop yields.
- Desirable pH value of 8.2 which suits plant growth and also facilitates as a buffer for slightly acidic soils.
- The trace metal leachability after column leaching test is well below the USEPA standards and therefore, no threat to

health, water bodies or environment for utilizing as a backfill material in clay mines.

Hence, BA can be used as a potential fill material for in rehabilitation of abandoned in clay mines.

4.2 Recommendations for future studies

- Different mixtures of BA and locally available soils need to be tested as it might improve the compaction properties and also for soil amendment purposes to obtain a suitable soil cover for recreational activities.
- Suitability of BA as a soil amendment need to be evaluated by seed raising experimental tests to select proper crops for vegetation.
- Long-term effect on utilizing BA should be investigated for safer application in the field without any threat for health and environment.

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