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# Evaluation of Coal Bottom Ash Properties and Its Applicability as Engineering Material

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**Abstract.** Coal ash is obtained in the combustion of coal for electricity production in coal based power stations. The non-combustible by-product including bottom ash and fly ash are discarded as a landfill. Consequently, the hazardous elements contained in the ashes can adulterate the ground and surface water. This study was carried out to emphasize the engineering properties of bottom ash collected at Tanjung Bin power station. An experimental study was carried out for particle size analysis, specific gravity, shear strength, compaction and relative density. The results depict that bottom ash possess particle size distribution nearly identical to sand, low specific gravity and dry density as compared to natural soil and having higher internal friction angle closer to granular materials. Based on the results, bottom ash can be employed in roadways, embankments and filling material for retaining walls by virtue of its low specific gravity, easy to compact and good frictional characteristics.

## 1. Introduction

Bottom ash and fly ash are obtained in the incineration of coal for steam generation in coal fired power plant. About 20% of the coal ash is reused while the remaining 80% is disposed of in landfills [1]. The discarded ashes in landfills threat to environmental sustainability. Several researchers investigated to reuse these coal byproducts to adhere to sustainable waste management. Sippert Santarema et al. [2], Lopes et al. [3] and Lynn et al. [4] stabilized the road structure with the utilization of coal ashes. These coal ashes are incorporated in mortar and concrete to partly replace cement and natural aggregates [5], [6]. The usage of the coal ashes relies on the chemical and physical properties of the coal bottom ash (CBA) and fly ash.

In combustion, a certain amount of the coal ashes stuck on the steam pipes and walls of the furnace to make clinkers. These clinkers fall down to the bottom section of the furnace and combine with the particles which settle down from the suspension of flue gases. The ash gathered in the lower portion of the furnace is refer as CBA. The CBA add up 20% to the total ash [7-10] CBA composed of irregular granular particles containing cavities and pores as compared to fly ash. CBA mainly consists of alumina, silica and iron along with trace quantity of magnesium sulphate and calcium etc. CBA has been shown to be a cost-effective material and possesses satisfactory engineering characteristics. Bottom ash express well-graded particle distribution and sufficiently high permeability, which enable geotechnical engineers to utilize in direct interaction with impermeable materials. CBA also possess low compressibility and high shear strength [4, 10]. As a result of these behaviours, the bottom ash can be considered as a suitable construction material for dam embankments, highways and other civil projects.



The need for coal for electricity production is increasing in coal operated plants in Malaysia. Coal is an easily available and cost-effective source of fossil fuel [11]. The Tanjung Bin power plant generate 42000MT of coal fly ash and 8000MT of CBA on a monthly basis [12]. The fly ash obtained from the plant is sold to cement manufacturer, but CBA is discarded in a storage ash pond. In the next few years, the operator will face the problem to transfer the solid waste to another ash pond. This research is conducted to examine the characteristics of Tanjung Bin CBA to reuse as a sustainable material.

**2. Materials**

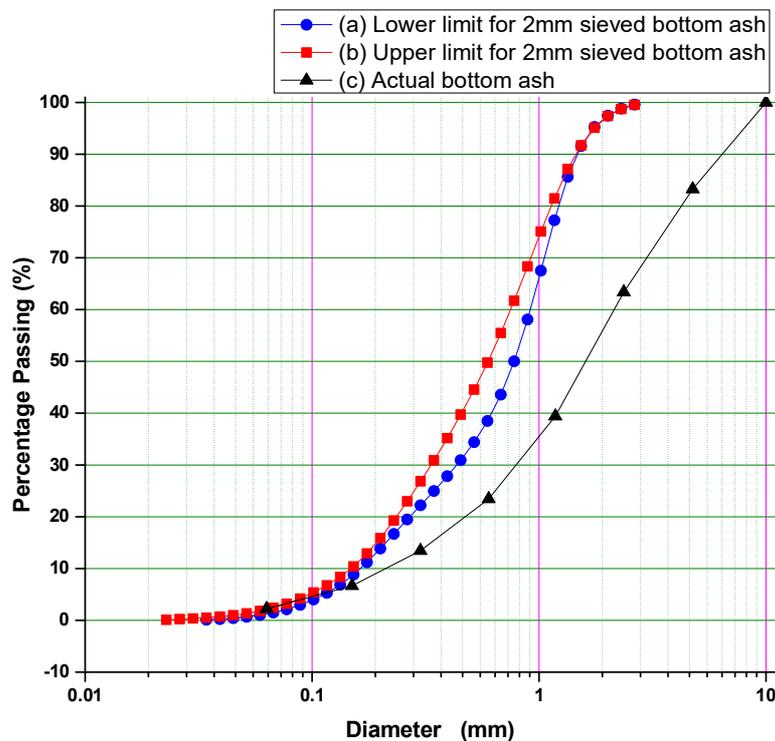
The CBA used in this research was collected near the disposal point at Tanjung Bin coal operated power station. The collected sample of CBA consists of various size particles less than 10mm. The sample was placed in an oven at 105-110°C for 24 hours. After drying the CBA was passed through 2mm sieve prior to the experimental setup.

**3. Result and discussions**

The physical and mechanical properties tests were conducted on the CBA sample. The experimental results are compared with the previous studies.

*3.1. Particle size distribution*

Sieve analysis and particle size analysis were conducted for the bottom ash to achieve the gradation curve. The particle size gradation was carried out for the sample using various size sieves and dry method for particle size analysis in accordance with BS Standard BS 1377:1990 [13]. Figures 1(a) and (b) present the lower and upper limit of the particle size distribution for bottom ash passed through 2mm sieve using laser diffraction particle size analyzer [PSA].



**Figure 1.** Particle size distribution curve for coal bottom ash: (a) and (b) The lower and upper limit of grain size distribution respectively, using laser scattering particle size analyzer for 2mm sieved bottom ash, (c) The particle distribution for bottom ash as received from disposal point.

The particle size analyzer using laser scattering method considerably reduces the effort and time needed for a sample [14]. Sieve-hydrometer analysis involves considerable time to complete several steps over a few days while laser diffraction is a quicker method that needs a few minutes for entire measurement. PSA provides more precise and detail data than traditional methods by constructing the overall particle size gradation and also need less amount of sample [15] The accuracy of PSA for coarser particle size usually reduce [16]. The coal bottom ash collected from the disposal point was dried and then passed through different sieve sizes and the particle distribution curve is presented in Figure 1(c). The grain size distribution graph shows that bottom contains 63% sand content and 37% gravel particles and classified as well-graded gravelly sand. The coefficient of Uniformity (Cu) for coal bottom ash is 10.90 and coefficient of curvature (Cc) is 1.21. The Cu for Tanjung Bin plant ranges from 6.43 to 16.56 while Cc ranges between 1.01 and 1.27 with other researchers [12, 17-18].

### 3.2. Specific gravity

The specific gravity (G) of the CBA was measured using small pycnometer method as stated in BS 1377-2:1990. The bottles with CBA and desiccator for determining the specific gravity is shown in Figure 2. The Tanjung Bin CBA has a specific gravity of 2.28. Previous researchers found the G value of Tanjung Bin CBA in the range of 1.99 and maximum of 2.41 [12, 17-19]. The G value of CBA is less than as compared to natural soils (2.50-2.7) and the lower specific gravity is justified by its particle structure and lower proportion of iron oxide. The value of G is directly related to the iron percentage if their proportion is more than 10% [20].

### 3.3. Compaction

The compaction behaviour of the CBA was determined by conducting standard proctor test in accordance with British Standard 1377-4: 1990 [21]. Figure 3 presents the relationship between dry density and water content. The maximum dry density and optimum water content from the compaction curve are 1.12 Mg/m<sup>3</sup> and 24% respectively. The maximum dry density ( $\gamma_{dmax}$ ) and optimum moisture content (OMC) for the Tanjung Bin CBA in previous studies range between 1.10 to 1.34 Mg/m<sup>3</sup> and 22 to 24.5% respectively [12, 17]. The maximum dry density of coal bottom ash is lower than sandy soil (1.7-2 Mg/m<sup>3</sup>). The compaction behaviours are controlled by several factors such as iron content, carbon content, fineness and gradation [20]. Bottom ash is beneficial in structural fill built on soft soil due to its lower dry density.

### 3.4. Relative density

The relative density is an important parameter to understand the loose and dense state of the coal bottom ash. The relative density test was carried out according to BS 1377-4:1990. The general expression used to specify the relative density in the laboratory is stated in Equation (1).

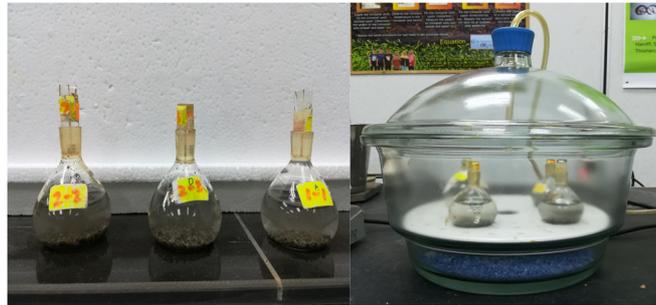
$$D_r = \frac{\gamma_{d \max}}{\gamma_d} \left[ \frac{\gamma_d - \gamma_{d \min}}{\gamma_{d \max} - \gamma_{d \min}} \right] \times 100 \quad (1)$$

$\gamma_{d \max}$  = Relative dry density at densest state,  $\gamma_{d \min}$  = Dry density at loosest state,  $\gamma_d$  = Dry density for a specific void ratio. Relative density gives a better demonstration of the deformation and strength than the void ratio of soil. The minimum relative dry density and maximum dry density for the coal bottom ash are 0.891 and 1.059 g/cm<sup>3</sup> respectively. The results show good agreement with the relative density indexes of the previous study [12].

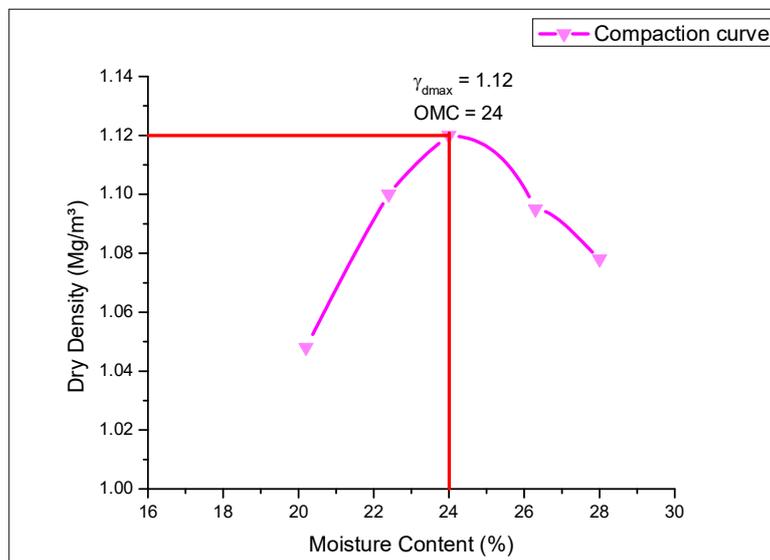
### 3.5. Direct shear test

The strength of coal bottom ash is an important parameter required in various geotechnical applications. The direct shear test was conducted on dry CBA employing densest relative density in accordance with BS 1377: Part 7: 1990. Figure 4 shows the laboratory setup of the direct shear test for CBA. The internal friction angle and cohesion for the coal bottom ash are 31.78° and 10.76 kPa correspondingly. The angle of internal friction ranges from 30.53 to 38.83 degrees and cohesion between 1.36 to 11.81 kPa with

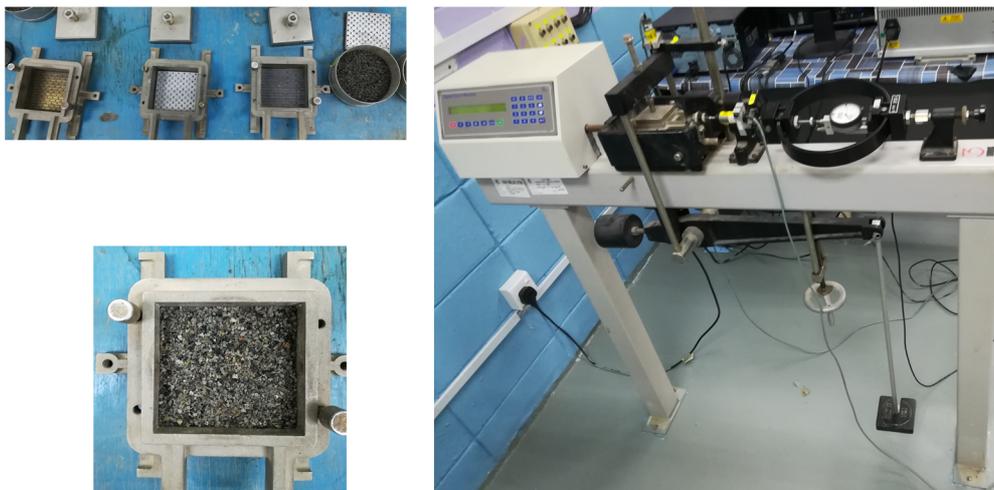
previous researchers [12, 17-18]. The CBA has a higher internal friction angle similar to that of traditional granular material.



**Figure 2.** Desiccator with specific gravity bottle filled with bottom ash and water.



**Figure 3.** Compaction curve for Tanjung Bin coal bottom ash.



**Figure 4.** Direct shear test apparatus and mould filled with bottom ash.

#### 4. Conclusions

This study was carried out on the engineering properties of Tanjung Bin coal bottom ash. Based on the experimental results, the Tanjung Bin CBA hold particle size distribution identical to that of natural sands, low dry density and specific gravity as related to soil and hold higher friction angle. The bottom ash has a better capability for usage as a construction material, particularly for geotechnical constructions. The bottom ash can be employed in the construction of roadways, embankments and as fill material in retaining walls due to its higher shear strength, easy to compact and lower specific gravity. The utilization of bottom ash will settle the issue related to dumping and will also contribute to environmental sustainability.

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