Geotechnical Characteristics of Tanjung Bin Coal Bottom Ash

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Abstract. Coal is considered one of the major sources of power-generation in Malaysia. The Coal-fired power plant is a kind of power plant that uses coal to generate electricity. The globally increasing demand for energy has led to an increase in the number of installation of coal-fired power plants. With the growth in coal-burning power plants, massive amounts of coal bottom ash have been produced as waste material. This article presents an experimental study on the geotechnical characteristics of Tanjung bin coal bottom ash and compares them with the properties of the natural granular soil focusing on the physical and mechanical characteristics namely; grain size distribution, specific gravity, compaction, permeability, shear strength, and relative density. Results revealed that the Tanjung bin bottom ash has geotechnical properties similar to the natural granular material, therefore it can be utilized as a substitute material to sand in several geotechnical application.

1. Introduction

Tanjung Bin power plant is one of the biggest coal-fired thermal plants in Malaysia with a generation capacity of 2100 MW(700 MW × 3 units) and coal-burning of 18,000 tonnes per day [1]. Due to the large usage of coal for the production of electricity, a huge amount of waste material daily produces. According to [2] the generation of electricity using coal-burning annually produce massive quantities of coal ash in forms of fly ash, bottom ash and boiler slag. However, the main components produce are fly ash and bottom ash [3–7].

The coal-burning of the Tanjung bin power plant daily produce about 180 tonnes of bottom ash and 1,620 tonnes of fly ash. This coal ash usually disposed of in open dumping sites near to the thermal power plant and it becomes a considerable concern to the power plant company because of the needs of ash storage space [1]. Moreover, it will cause environmental hazards [8] since it contains heavy metals concentration.

The chemical compounds of Tanjung bin bottom ash were studied by numerous researchers in the literature [1,9–11]. The authors performed X-ray diffraction and X-ray fluorescence analysis on some samples obtained from Tanjung bin plant; they found that the main constituents are Silica (SiO₂) with percentage of 33.7%, 42.7%, 45.3 and 46.6%, Alumina (Al₂O₃) with percentage of 12.9%, 23.0%, 18.1 and 26.1% and Iron oxide (Fe₂O₃) with percentage of 6.98%, 17.0%, 19.84 and 12.4%
respectively. Based on ASTM C618, Tanjung bin bottom ash can be categorized as Class F, whereas the total of silica (SiO₂)+ alumina (Al₂O₃)+ iron oxide (Fe₂O₃) exceeds 70% [12].

The engineering characteristics of the bottom ash material have a great influence on the use of various construction applications. This paper intended to study the geotechnical properties of Tanjung bin bottom ash in particular physical and mechanical properties and compared them with natural granular material.

2. Experimental Program

The coal bottom ash material was used in this study had been collected from Tanjung bin thermal power plant, Johor. Figure 1 presents the location of the thermal power plant. The testing samples were taken from the ash pond area.

Figure 1. Tanjung bin thermal power plant location.
The testing program was conducted to examine the geotechnical characteristics of Tanjung bin bottom ash, which includes the physical properties: particle size distribution, specific gravity, and permeability, as well as the mechanical properties: compaction, shear strength and relative density. The physical and mechanical properties were conducted according to British Standard (BS) and American Society of Testing Material (ASTM). Figure 2 shows a sample of the testing material.

Figure 2. Sample of Tanjung coal bottom ash.

3. Results and Discussion

3.1 Particle Size Distribution
The grain size of Tanjung bin bottom ash was determined following the British Standard 1377: Part 2: 1990 and the test results obtained were illustrated in Figure 3. From the distribution curve, it can be seen that; the bottom ash has grain size varied from 0.063 mm to 20 mm. Moreover, the coefficient of curvature was noticed as 1.15, while the coefficient uniformity was found as 9.63. From the published literature, a lower value of the coefficient of curvature and uniformity for Tanjung bin bottom ash was reported as 1.01 and 6.43 respectively; whereas the highest value was found as 1.27 and 16.56 respectively [1,13]. Based on the Unified Soil Classification System (USCS), Tanjung bin bottom ash can be categorized as well-graded sand (SW), while from AASHTO system it can be classified as A-1-a.

Figure 3. Grain size distribution Curve.
3.2 Specific Gravity
The specific gravity of Tanjung bin coal bottom ash was determined according to British Standard 1377: Part 2: 1990 through conducting a small pycnometer test as shown in Figure 4. The specific gravity was achieved as 2.23. However; the specific gravity of Tanjung bin bottom ash was found by previous researchers in the range between 1.88 Mg/m³ and 2.44 Mg/m³ [10,14]; while the specific gravities of the natural soils fall between 2.5 Mg/m³ and 2.8 Mg/m³ [15] and the average specific gravity of sandy soil is 2.65 Mg/m³ [16]. According to these results, it can be seen that the specific gravity of Tanjung bin bottom ash is lower than the natural soil and this is can be mainly due to the different chemical compounds which contain lower iron oxides as well as due to the different grain structure [1].

![Figure 4. Small pycnometer test.](image)

3.3 Permeability
The drainage characteristic of Tanjung bin coal bottom ash was examined by performing a constant head permeability test and it’s conducted following the British Standard 1377: Part 5:1990. Figure 5 shows the testing equipment and setup. The coefficient of permeability was found as 2.41 x 10⁻¹ cm/s. From the literature the coefficient of permeability of Tanjung bin bottom ash was reported between 6.09 x 10⁻¹ cm/s and 1.72 x 10⁻² cm/s [1,11,13,17–20], however lower values of 1.47 x 10⁻² cm/s and 6.88 x 10⁻³ cm/s were reported by [21,22] respectively. According to [16], the permeability of fine sand ranges from 10⁻¹ cm/s to 10⁻³ cm/s. Considering the Unified Soil Classification System (USCS); Bottom ash can be also categorized as good draining material such as gravel and sand.
3.4 Compaction

Standard proctor compaction test was performed according to British Standard 1377: Part 2: 1990. The relationship between the moisture content and the dry density is illustrated in Figure 6. From the compaction curve, the optimum moisture content of the bottom ash was found as 24.5% while the maximum dry density was 1.10 g/cm$^3$. The compaction test results obtained by previous researches revealed that the optimum moisture content of Tanjung bin bottom ash varied from 22 to 24% whereas the maximum dry density ranges between 1.131 g/cm$^3$ to 1.34 g/cm$^3$ [1,11,13,14-19]. However [16] reported that the dry density of the sand soil falls between 1.7 g/cm$^3$ and 2.0 g/cm$^3$, therefore bottom ash can be considered as a light material compared to the sand.
3.5 Relative Density
Based on ASTM D4253 and ASTM D4254, the relative density test can be only used to the soil having fine content (silt or clay) less than 15%, and exhibit good draining characteristics. From the sieve analysis test results for the Tanjung Bin bottom ash sample, it was found that the silt or clay contents about 2%. Therefore, the relative density test is suitable for predicting the density of the bottom ash. The relative density of coal bottom ash was conducted according to ASTM D 4253. The test results revealed that the minimum dry density of Tanjung Bin bottom ash is 0.896 Mg/m³ while the maximum dry density is 1.120 Mg/m³.

3.6 Shear Strength
The shear strength parameters of soil are defined by cohesion and angle of internal friction. The direct shear test was performed to determine the shear strength parameters of Tanjung bin bottom ash. The test was conducted following to British Standard 1377: Part 2: 1990. The test results show that the cohesion of the bottom ash is 11.81 kPa while the angle of internal friction is 30.57°. However, the most cohesion values of Tanjung bin bottom ash reported in literature falls between 1.36 kPa to 9.89 kPa and the angle of internal friction ranges between 30° and 38.83° [1,17,20,21,23–24].

Muhardi et al. [1] conducted a Triaxial test on compacted saturated bottom ash samples to determine the drained and undrained shear strength parameters of bottom ash specimens collected from the Tanjung bin power plant. For the drained condition, the angle of internal friction was found as 46°, while for the undrained condition the angle of internal friction was reported as 44°. Furthermore, the effective shear strength of Tanjung bin bottom ash was studied by [23] through preforming Consolidated Undrained Triaxial test with pore pressure measurement. The apparent cohesion was found as 27.66 kPa and the effective friction angle was 31°. According to [25], the lower value of angle of internal friction of sand soil is ranging between 27° and 37°, whereas the higher value falls between 32° and 50°; however [15] reported that the angle of internal friction of sand soil is ranging between 26° and 45°, therefore, the angle of shearing resistance for Tanjung bin bottom ash falls within the range of sand soil.

4. Conclusion
This paper attempted to study the physical and mechanical properties of Tanjung bin bottom ash material. The results indicated that Tanjung bin bottom ash is distributed from fine sand to fine gravel with lower specific gravity compared to the natural granular material. This is an advantage in the construction of embankment or fills on the soft ground has a low carrying capacity. Also, Tanjung bin bottom ash as well-graded and free drainage material is suitable to be used as backfilling material because it can prevent the development of pore water pressure in the fills or embankments. Therefore, the utilization of bottom ash in considerable amounts as construction material such as; embankments and filling material can help to solve the disposal problem of the bottom ash as well as it can minimize the environmental impact.

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