Effect of Alkali-Activator to Bottom Ash Ratio on the Undrained Shear Strength of Bottom Ash based Geopolymer

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Abstract. Coal ash is generated as a raw product during combustion in thermal power plants. These industrial wastes include fly ash and bottom ash, which has been deemed as a source materials for geopolymer. Bottom ash is used in soil columns for stabilizing foundation soil. In the present study bottom ash from Tanjung bin power station was used as a substitute materials for making geopolymers. The effect of alkali activator to bottom ash ratio on the undrained shear strength of bottom ash based geopolymer was studied. The molarity of sodium silicate solution was kept as 14, $Na_2SiO_3/NaOH$ of ratio 2.5, mass ratio of alkali activator to bottom ash 0.40, 0.50 and 0.60, and steam curing at 65ºC were attempted for the samples. The experimental results of UU triaxial test indicate that alkali-activator to bottom ash ratio of 0.50 gives higher undrained shear strength.

1.0 Introduction

Each year, the utilization of fossil fuels for energy production increased. Coal is used as a fuel to produce steam for electricity generation and industrial functions. The raw product obtained as a coal ash requires to be discarded in an environmentally safe approach. These coal ash mainly include fly ash (80% of raw product) and bottom ash (20% of raw product) are discarded as a landfill. This dumping process tends to environmental issues.

The fly ash minimizes the heat of hydration and enhances the durability and workability of concrete by replacing some proportion of cement [1]. In contrast, bottom ash (B.A) does not hold the same workability and other properties. The chemical content of fly ash and bottom ash are almost identical, but the size and shape of both materials are different. Bottom ash composed of coarser and irregular particles having voids and cavities. Bottom ash can be used as substitute component in concrete to minimize the usage of ordinary Portland cement (OPC) [2-5] and also in stone columns for soft soil stabilization [6-8].

Ordinary Portland cement concrete needs a large number of raw products which achieved through energy-intensive operations that result in generation of greenhouse gases such as CO_2, NOx. About one ton of CO_2 is produced for one ton OPC production and approximately 1.35 billion tons per year CO_2 is generated due to OPC production, which adds 7% to the greenhouse gases released to the atmosphere [9-10]. The OPC industries offer a real challenge to environmental sustainability. Hence, geopolymer is considered as a green and environmentally friendly material to decrease the consumption of OPC. The

geopolymerization process needs alumina and silica-rich source materials such as kaolin, fly ash and bottom ash.

In Malaysia, the coal operated power stations are achieving emphasis due to increase in demand for energy and need for cleaner technology. Coals are considered as a feasible fuel source in the forms of supply and cost [11]. Tanjung Bin is among the largest coal power stations to produce electricity. Every month, 8,000 metric ton (MT) bottom ash and 42,000 MT fly ash are obtained from coal-burning [12]. This study focused on the basic properties of B.A collected from Tanjung Bin power station. The undrained shear strength of bottom based geopolymer was determined for alkali activator to bottom ash ratio of 0.40, 0.50 and 0.60.

2.0 Materials and methods

The particle size gradation was performed according to the British Standards BS1377:1990. Specific gravity for bottom ash was determined using small pycnometer method. Standard proctor test was conducted for compaction behaviours.

The sodium hydroxide (NaOH) at 14 molarity was used for geopolymer sample preparation. The premixed alkaline solution was kept for 24 hours at ambient temperature [9]. The proportion of sodium silicate (Na_2SiO_3) to NaOH was selected as 2.5. The bottom ash used in this research passed through 2mm sieve. The mixture of bottom ash, NaOH and Na_2SiO_3 were compacted in three layers using cylindrical molds having a diameter of 38mm and height of 76mm. The samples were sealed with a lid to protect the moisture loss and placed at a temperature of 65°C for 48 hours [1, 13]. The undrained shear strength for bottom ash based geopolymer was determined for 3, 7, 14 and 28 days according to British Standards [14].

3.0 Result and discussions

The particle size distribution, specific gravity and compaction results for B.A and undrained shear strength (USS) of bottom ash based geopolymer are discussed as:

3.1. Particle-size distribution and specific gravity

The grain size distribution for B.A is shown in Figure 1. The bottom ash particles lie between 10mm and 0.063mm and ranging between coarse gravel and fine sand. Hence, the bottom ash is classified as coarse-grained material. The bottom is assigned as well-graded gravely sand in accordance with the unified-soil classification system. The specific gravity value of B.A is 2.28, which is less than the specific gravity of fine aggregates and coarse sand. The specific gravity of B.A depends on the porosity of particles and iron oxide contents [15].
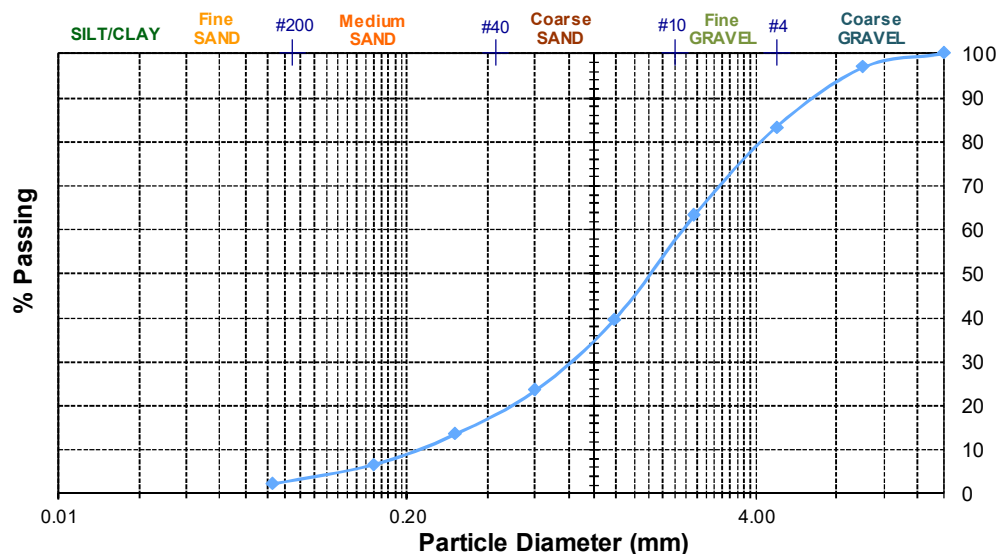

Figure 1. Grain-size distribution curve for the B.A

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3.2. Compaction test

The standard proctor compaction procedure was performed for determining the maximum dry density (γ_d) and optimum moisture content (OMC). Figure 2 presents the compaction curve for the bottom ash. The γ_d and OMC for the Tanjung Bin power plant are 1.12 Mg/m^3 and 24 % respectively. The maximum γ_d of the B.A is lesser than that of sandy soil (1.7—1.2 Mg/m^3).
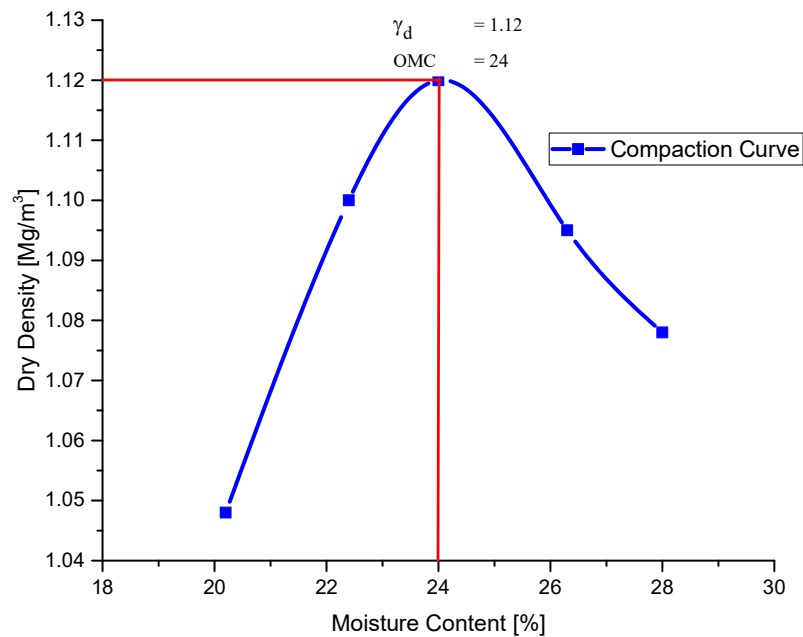

Figure 2. Compaction curve for the bottom ash.

3.3. Undrained shear strength

Soft soils are improved with stone columns [16-17] and soil-cement columns [18-19]. Different columns materials are used to stabilize the soft soil. B.A is a by-product of coal combustion and used in stone columns. Limited literature is available on the characteristics of B.A based geopolymer. Some researcher investigated the compression strength of B.A based geopolymer concrete [9, 20]. However, there is no literature available up to author knowledge on the undrained characteristic of B.A based geopolymer.

The undrained shear strength of alkali-activated B.A with different curing period is shown in Figure 3. The results explicit that undrained shear strength (Cu) enhanced with the curing period. However, Cu tends to drop after 14 days curing period. This effect is more prominent for 0.40 and 0.60 alkali activator to bottom ratio. The compressive strength against curing period follows the same trend with other researchers for coarser size bottom ash [9, 21]. Figure 4 describes the stress-strain curve of 14 days curing period for 0.50 solution to bottom ash ratio. Based on the undrained unconsolidated test curve, the behaviour of bottom ash based geopolymer follow brittle pattern with deviator stress reached the peak and abruptly fall.
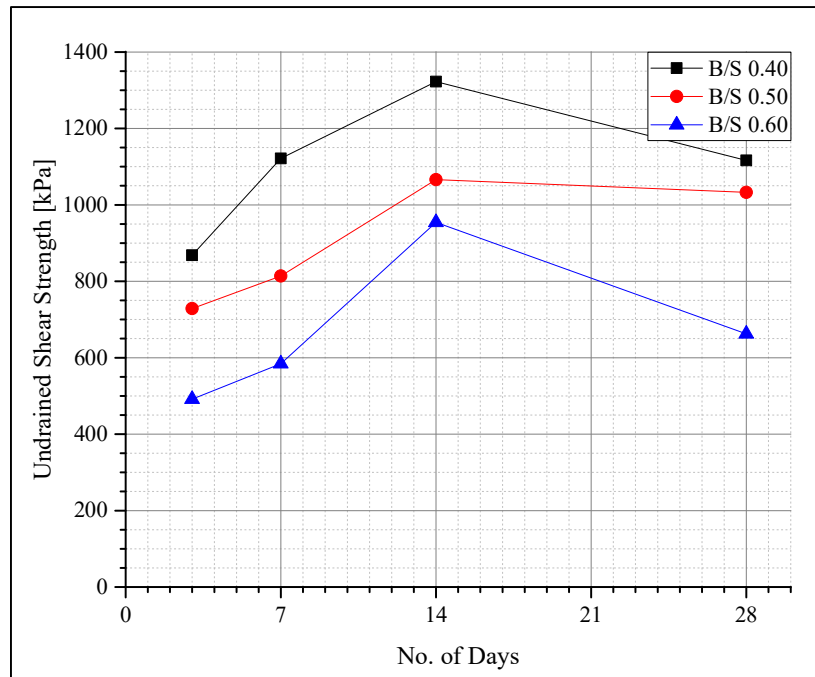
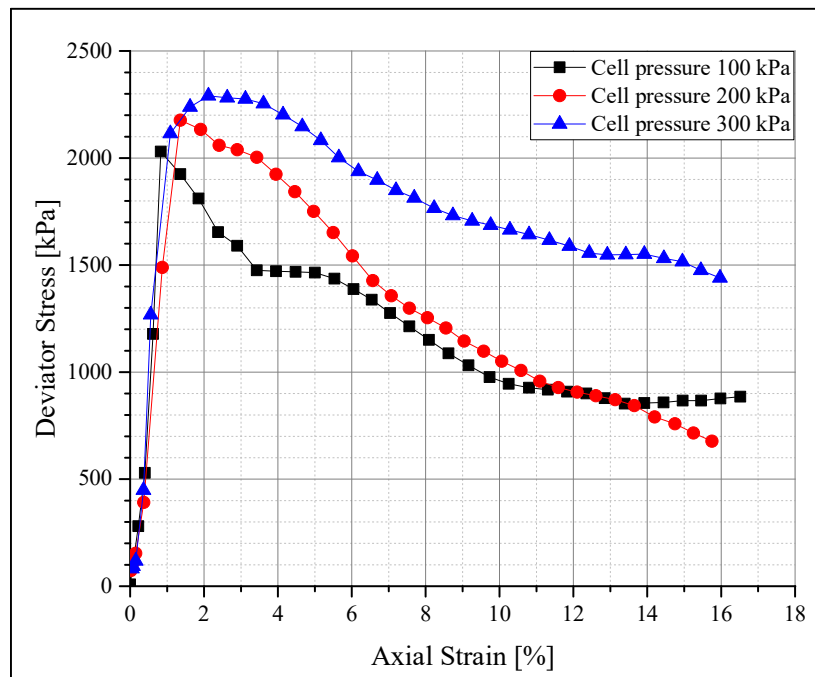**Figure 3.** Undrained shear strength versus curing period.

Figure 4. Deviator stress against axial strain for various confining pressure.

4. Conclusions

This paper presents an experimental study on the basic properties of B.A such as sieve analysis, specific gravity, compaction and undrained shear strength behaviour of bottom ash based geopolymer. The undrained unconsolidated tests were performed for three alkali activator to bottom ash ratio at different curing period. The results reveal that bottom ash based geopolymer achieve high strength at early curing

period, but the Cu value tends to lower after 14 days curing for 0.40 and 0.60 solutions to B.A ratio. Based on the UU test results, the study suggests the alkali activator to B.A ratio of 0.50 for good geopolymerization process.

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