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Shear Strength Improvement of Soft Clay Mixed with Tanjung Bin Coal Ash

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Abstract

Coal is one of the world's most important sources of energy. The burning of coal produces coal ash that mostly consists of bottom ash (BA) and fly ash (FA). However, the utilization of coal ash in civil engineering construction applications has just received some attention within the last decade. This paper presents the strength improvement of soft clay mixed with coal ash. Kaolin was used to represent soft clay; mixed with 20%, 40% and 60% of BA and FA independently by weight. The optimum moisture content of kaolin was used in the mixing. Strength properties of mixtures had been carried out by conducting direct shear test and unconfined compression test. By adding FA to kaolin, the value of shear strength increased between 12 to 39 times the initial strength at different curing periods due to the pozzolanic reactions. From direct shear test of uncured mixtures, both kaolin – FA and kaolin – BA mixtures had similar strength at 40% - 60% FA or BA. Beyond this value as the percentage of FA increased the shear strength decreased but the increase in BA content increase the strength of mixture further.

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Keywords: kaolin; fly ash; bottom ash; direct shear test; unconfined compression test.

1. Introduction

Construction work includes earth dams, road embankment and other structures on soft clay require ground

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improvement or modification technique to improve its properties. There are many available methods to improve the properties of soft clay soil such as piling, sand drain, using admixtures and many more methods. This paper concentrates an effect of adding coal ash on soft clay improvement. Coal is one of natural resources that existed due to the chemical and geological alteration of materials formed by plants over tens or hundreds of millions of year in the past [4]. It is being used extensively by power generation plants to produce energy for electricity [2]. However, disposal of coal ash becomes environmental important issues and number of production is abundant. Therefore, to reduce the disposal problem of coal ash, the study would provide the basic requirements for determining the feasibility of using coal ash produced by Tanjung power plant in construction industry mixed with soft clay soil. [1]; [8];[9];[10] and [11] have conducted a research using fly ash and bottom ash. Besides that, the environmental and disposal space problems could be later saved and reduced.

In the present paper, three objectives were focused to present improvement of soft clay mixed with coal ash. The objectives are:

I. To determine the physical properties of kaolin, FA, BA and different mixing percentages of kaolin + FA and kaolin + BA.
II. To determine the shear strength of soft clay mixed with FA and with BA independently in various percentages.
III. To compare the effect between the addition of FA and the addition of BA on the improvement of shear strength of soft clay at different curing time.

2. Characteristics of Kaolin and Coal Ash

Clay has particle sizes less than about 0.002mm or easily break down to this size [7]. For white kaolin, reported that the specific gravity vary from 2.60 to 2.66, liquid limit 42%, plastic limit 21% , and optimum moisture content, w_{opt} of 18% while maximum dry density; ρ_{dmax} was 1.64 Mg/m^3 [3][11]. For BA generally is a coarse, granular in shape material with grain size ranging from sand to gravel [6]. The specific gravity varies from 1.9 to 2.66, while the w_{opt} and ρ_{dmax} were 22% and 1.310 Mg/m^3 respectively [10]. Thus far, the FA has particle size distribution from 0.001 to 2mm. The specific gravity was ranging from 2.19 to 2.30, and w_{opt} vary from 19% to 20% while the ρ_{dmax} was ranging from 1.530 to 1.568 Mg/m^3 [5] [1] [10].

3. Materials and Methods

Kaolin was mixed with water and compacted to have homogeneous strength. The optimum moisture content obtained from the kaolin compacted using standard proctor compaction test had been used when kaolin was mixed with FA and BA (obtained from Tanjung Bin Power Plant), independently. All samples used were oven dried and stored inside plastic bags to maintain their dry condition. Blends of coal ash and soft clay were prepared by weight into three different percentages as follows:

1. 20% Kaolin + 80% FA or BA independently.
2. 40% Kaolin + 60% FA or BA independently.
3. 60% Kaolin + 40% FA or BA independently.

Laboratory works contained both physical and mechanical properties of mixing soft clay with coal ash in various percentages. By doing these, the first leg was to evaluate the material characteristics. After the optimum moisture content was obtained from the standard compaction test on kaolin, all mixtures were then compacted using this moisture content. Samples of compacted mixtures were tested in laboratory for direct shear and unconfined compression test. Kaolin mixed with FA had been cured at 0, 14 and 28 days. The laboratory tests were based on BS 1377 (1990).

4. Results and Discussions

4.1. Specific gravity

The result shows that the value of specific gravity of kaolin was 2.56. The value was quite low compared to [11] [3], while within the range of the value obtained from natural soils that had in the range of 2.5 to 2.7 [10]. However, the specific gravity of BA was 2.44. The value was significantly high compared to [10]. Meanwhile, the value indicates that the specific gravity of BA is varying from day to day production over time even from the same source due to its dense nature of BA [5]. For FA, the specific gravity was 2.22. The value was quite lower according to [5]. Besides that, the current value was significantly similar to research done by [1].

4.2. Particle Size Distribution

Fig 1 shows that the particle size distribution of kaolin, BA and FA used in this study. Generally, kaolin clay was well graded, ranged from clay to fine sand. The majority of the sizes occurred in a range between 1.00mm and 0.002mm which is sand and silt area according to BS 5930. However, according to AASHTO classification system kaolin was in A-4 group. For FA, the particle size distribution was ranged mostly from silt to fine sand sizes base on BS5930. Meanwhile, based on classification of AASHTO system the particle size distribution of FA was in A-4 group. The gradation of BA was well graded size distribution. The majority sizes occurred in a range between 14 mm and 0.065mm which is from fine sand to fine gravel sizes according to BS 5930. For AASHTO classification system, the BA was in A-1-a group.

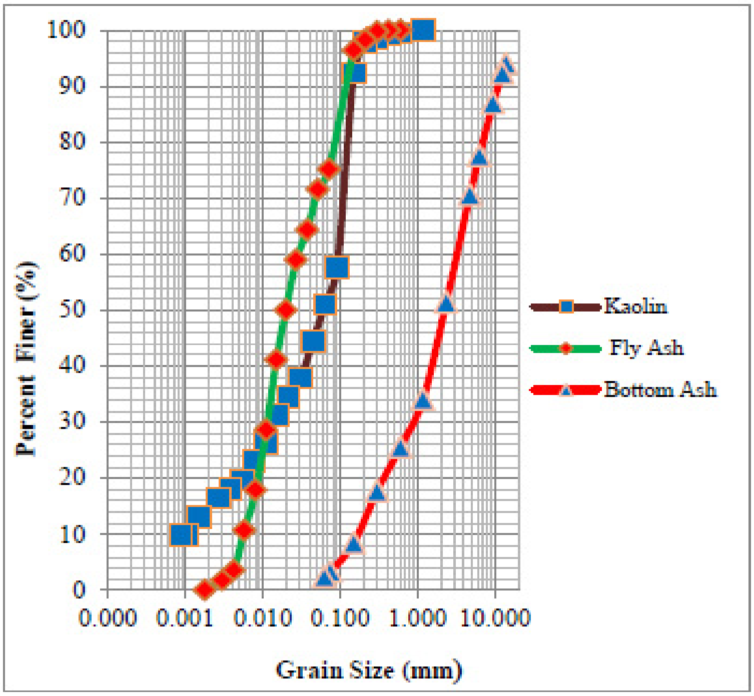

Fig. 1. Grain size distribution of kaolin, bottom ash and fly ash

Fig 2 shows the grain size distributions of BA and FA mixed with kaolin independently in different percentages. For kaolin mixed with BA, the grain size distribution was classified as sand to fine gravel sizes base on BS 5930. Thus, more content of BA in the mixture produced more gravel. It means that the mixtures with higher BA composition have better-graded particle size distribution compared to the mixtures with less composition of BA. On the other hand, kaolin mixed FA was classified as silt soils since FA and kaolin have same properties of grain size distribution. The results also shows that, as the FA content increased, the range of particle size distribution tend to be more to sandy area.

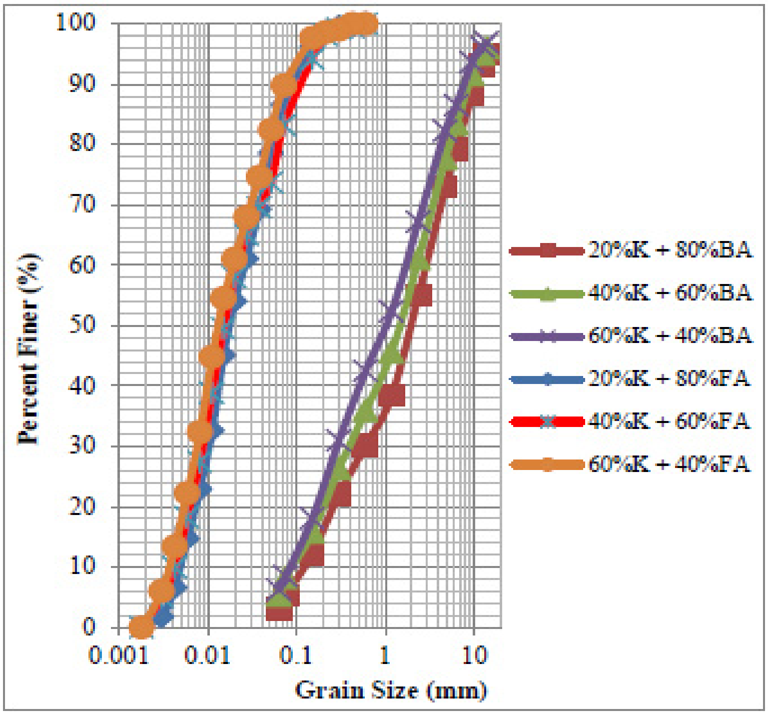

Fig. 2. Grain size distribution of kaolin mixed with bottom ash and fly ash in different percentages

4.3. Compaction

Fig 3 shows the compaction curve of kaolin, BA and FA. From the standard compaction test the optimum moisture content, wop and maximum dry density, ρ_{dmax} of compacted kaolin were 18% and 1.64 Mg/m^3 respectively. For FA, the wop and ρ_{dmax} were 19% and 1.595 Mg/m^3 respectively. According to [1], the wop of FA from Tanjung Bin was 19% while ρ_{dmax} was 1.568Mg/m^3. The result was similar to the current study of FA. However, BA has wop and ρ_{dmax} of 22% and 1.339 Mg/m^3 respectively. According to study done by [11], the wop of BA was 24% with the ρ_{dmax} of 1.320 Mg/m^3. Hence, the result was quite higher for the current result due to variation product of BA from day to day over time even from the same source.

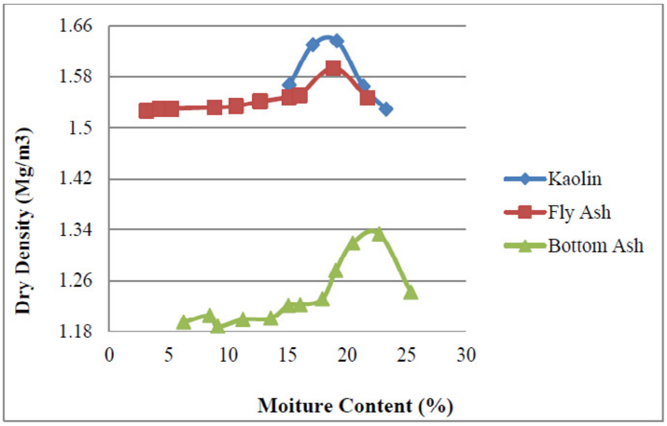

Fig. 3. Compaction curve of kaolin, bottom ash and fly ash

4.4. Unconfined Compression Test

Fig 4 and Fig 5 shows the results of unconfined compression tests of kaolin mixed with FA at different percentages. The value of the shear strength of kaolin mixed with FA was determined at 0, 14 and 28 days of curing period. At all curing periods the value of shear strength for the mixtures was increased whenever the value of FA increased. This result depends on the fly ash content in the mixtures. In addition to that, the shear strength of mixtures also increased with the increase of curing periods which might be due to the pozzolanic reactions and also some agglomerates bonded particles formed due to the crystal growth between kaolin and FA [12]. Fig 4 shows the variation of strength given by kaolin mixed with FA in different curing periods. The highest strength increment occurred at 20% kaolin + 80% FA at 28 days curing period as shown in Fig 5. It indicated that, the percentage of strength increment depend on the amount of FA in the mixture and curing periods.

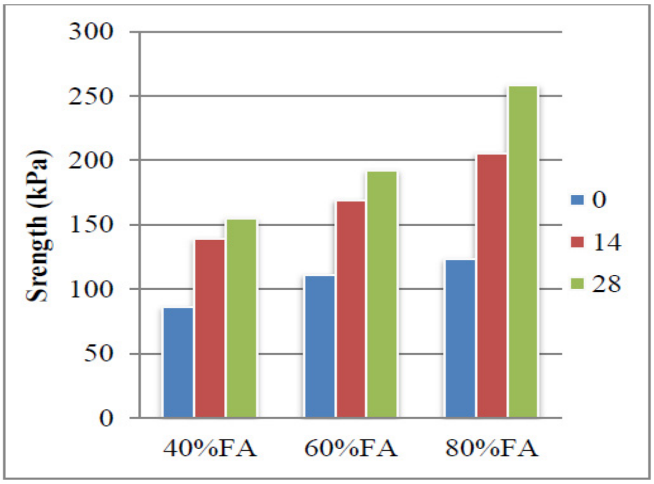

Fig. 4. Variation in strength of kaolin-FA with different percentages at different curing period.

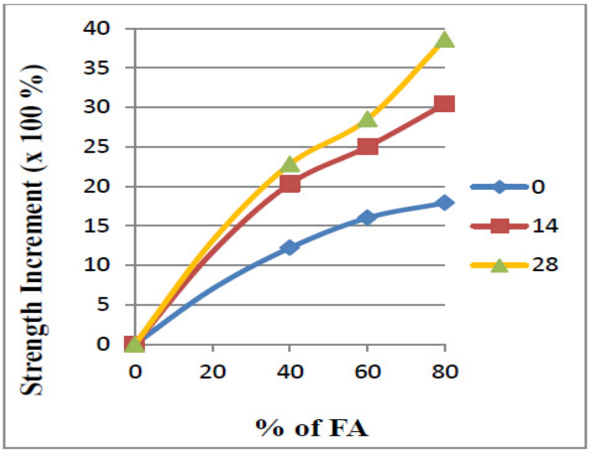

Fig. 5. Strength increment of kaolin mixed with FA at different curing period

4.5. Direct Shear

Fig 6 shows the values of cohesion increased at 40% and 60% of BA in the mixture while decreased at 80% of BA. For kaolin - FA mixtures the values of cohesion increased at 80% FA while decreased at 40% and 60% of FA. From the result shows that, different mixtures of kaolin with BA and FA exhibit different values of cohesion and friction angles. This was due to coarse-grained size of the coal ash which affects the shear behavior of the mixtures.

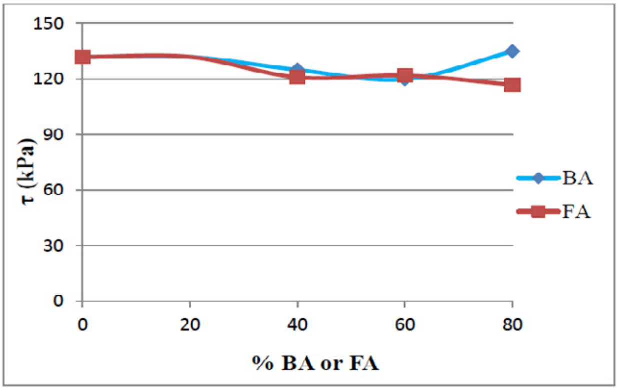

Fig. 6. Variation in Strength of Kaolin – BA or FA with different percentages of BA or FA

5. Conclusions

1. Kaolin had a liquid limit of 36%, plastic limit of 28%, and shrinkage limit of 27%. It has specific gravity of 2.56. It was well graded with the sizes ranged from fine silt to fine sand. From the standard compaction test the w_{opt} was 18% while ρ_{dmax} was 1.64 Mg/m3.
2. BA had been classified as well graded sand using soil classification system (USCS) and falls into group A-1-a using AASHTO classification system. It has specific gravity of 2.44. From the standard compaction test the w_{opt} was 22% with ρ_{dmax} of 1.339 Mg/m3.

3. FA used was in the group of A-4 for AASHTO classification system. It ranged mostly from silt to fine sand sizes base on BS5930. The majority of the sizes occurred in the range between 1.00 and 0.002 mm. The specific gravity value was 2.22. From the standard compaction test the w_{opt} was 19% with the ρ_{dmax} of 1.595 Mg/m3.
4. For unconfined compression tests of kaolin mixed with FA at different percentages was determined at 0, 14 and 28 days of curing period. The value of shear strength was ranged from 86 kPa to 123 kPa for none cured samples, 139 kPa to 205 kPa for 14 days cured samples, and 155 kPa to 258 kPa for 28 days cured samples. The value of shear strength increased between 12 to 39 times the initial strength at different curing periods due to the pozzolanic reactions of the added FA.
5. From direct shear test of uncured mixtures, it seems that both kaolin – FA and kaolin – BA mixtures had similar strength at 40% - 60% FA or BA. Beyond this value as the percentage of FA increased the shear strength decreased but the increase in BA content increase the strength of mixture further.

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References

[1] Awang AR, Marto A and Makhtar AM. Geotechnical Properties of Tanjung Bin Coal Ash Mixtures for Backfill Materials in Embankment Cosntruction .The Electronic Journal of Geotechnical Engineering (EJGE).Vol. 16/L 2011. pp1515-1531.

[2] Bruce GM. Coal Energy Systems. Elsevier Academic Press. (2005).

[3] Eisazadeh A, Khairul AK and Hadi N. Stabilization of tropical kaolin soil with phosphoric acid and lime. World Academy of Science, Engineering and Technology. (2011).

[4] Harold HS. The Energy of the Past and Future. American Chemical Society Washington, D.C. (1987)

[5] Kim BJ, Yoon SM and Balunaini U. Determination of Ash Mixture Properties and Construction of Test Embankment -Part A. Joint Transportation Research Program, Final Report, FHWA/IN/JTRP-2006/24, Purdue University, W. Lafayette, Indiana.

[6] Lee FW. Morphology, Mineralogy and Engineering Characteristics of Tanjung Bin Bottom Ash. Universiti Teknologi Malaysia. (2008)

[7] Liu C and Evett JB. Soils and Foundations. Pearson Prentice Hall, Singapore. (2005)

[8] Lokeshappa B and Dikshit AK. Behaviour of metals in coal fly ash ponds. APCBEE Procedia 1 (2012) 34-39. Doi:10.1016/j.apcbee.2012.03.007

[9] Marto A, Awang AR, and Makhtar AM. Compaction Characteristics and Permeability of Tanjung Bin Coal Ash Mixtures. 2011 International Conference on Environment Science and Engineering IPCBEE vol.8 (2011) © (2011) IACSIT Press, Singapore

[10] Muhardi, Marto A, Khairul KA, Makhtar AM, Lee FW and Yap SL. Engineering Characteristics of Tanjung Bin Coal Ash. The Electronic Journal of Geotechnical Engineering (EJGE) Vol 15K/2010. p 1117-1129, ISSN 1089-3032.

[11] Muzamir H, Marto A, Hyodo M and Makhtar AM. The Strength of Soft Clay Reinforced with Singular and Group Bottom Ash Columns. The Electronic Journal of Geotechnical Engineering (EJGE)Vol. 16/N 2011. pp1215-1227

[12] Sivapullaiah PV. Enhancement of strength of soft soils with fly ash and lime. Department of Civil Engineering, Indian Institute of Science, Bangalore, India .(2007)