Stabilization of Kaolin Clay Soil Reinforced with Single Encapsulated 20mm Diameter Bottom Ash Column

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Stabilization of Kaolin Clay Soil Reinforced with Single Encapsulated 20mm Diameter Bottom Ash Column

M Hasan[1,*], M S I Zaini[1], N A A Hashim[1], A Wahab[1], K A Masri[1], R P Jaya[1], M Hyodo[2], M J Winter[3], M Sholichin[4], R Haribowo[4]

[1]College of Engineering, Department of Civil Engineering, Universiti Malaysia Pahang, Lebuhraya Tun Razak 26300 Kuantan, Pahang Darul Makmur, Malaysia.
[2]Graduate School of Science and Technology for Innovation, Yamaguchi University, Ube, Japan.
[3]Hokoku Engineering Co., Ltd., 3-5-26, Daikoku-cho, Toyonaka-shi, Osaka 561-0827, Japan
[4]Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Jl. Veteran, Ketawanggede, Kec. Lowokwaru, Kota Malang, Jawa Timur 65145, Indonesia

*Corresponding author: muzamir@ump.edu.my

Abstract. Ground improvement methods are used to reduce the weakness of soft clay, which is low strength and high compressibility. The stone column technique involves replacing any of the soil with crushed stone such as broken rocks or sand which is an efficient method of improving the strength parameters of soil. Bottom ash usage in materials of building will effectively decrease the buildup of the waste and hence protect the environment. This study is to determine the shear strength of kaolin soft clay reinforced with a 20 mm diameter single encapsulated bottom ash column with various lengths. The research will look into the physicomechanical qualities of the materials used, including subsoil and bottom ash. Three (3) batches of samples with each batch consists of five (5) samples were prepared by using compaction method. All kaolin samples with a diameter of 50mm and height of 100mm with single encapsulated bottom ash columns with various lengths which are 60mm, 80mm, and 100mm were tested under Unconfined Compression Test (UCT). The result illustrated that the strength of samples increases as the height and volume of encapsulated bottom ash column increases.

Keywords: Construction industry, ground improvement, kaolin soft clay.

1. Introduction

Putting up the framework on shaky ground, such as soft clay is a common nowadays due to insufficient construction sites. Soft soils are accompanied by extreme porosity, low strength, and high shrinkage. Construction challenges in this deposit include low bearing capacity, severe post-construction subsidence, and instability during excavation and embankment creation [1].

Clay soils have low strength properties and lose hardness even more when wetted or subjected to additional physical commotions. They can be elastic and compressible, expanding when wet and contracting when dry. Some varieties expand and contract significantly when wet and dry. Under constant strain, Sandy soils can spread (elastic deformation distort) over time, especially when shear stress approaches stiffness, making them susceptible to disasters. They have poor resistance and large lateral stresses [2].

Soft soils are categorized into two types: those with a strength of less than 13 kPa, known as very weak soil, and those with a strength of less than 26 kPa, known as weak soil [3]. [4] defines soft clay as soils with a strength of less than 26 kPa. Undrained strengths from laboratory testing such as undrained triaxial and field vane shear tests are displayed against elevation. The data was then evaluated in order to produce a typical mean undrained shear profile as well as top and bottom undrained shear strength bounds [5].

Ground improvement is required to change the qualities of the soil. To enhance the soft soil, many approaches such as lime treatment, pre-consolidation acceleration using pre-fabricated vertical drains, and the most popular way, stone column, have been applied. Bottom ash is utilized as a fine aggregate alternative because it has qualities comparable to sand.

According to [6], bottom ash is produced in coal burners during the burning of coal in the burners of coal-fired thermal power stations. These particles are rough, irregular, amorphous, flaky, greyish in colour, and approximate incandescent lava in appearance. Bottom ash is thinner and more fragile than fine aggregate [6]. Bottom ash is mostly made up of silica, alumina, and iron, with trace amounts of calcium, magnesium, sulphate, and other elements. The source of the coal determines its chemical composition [7]. Furthermore, the use of pozzolanic materials improves the strength of any product that contains bottom ash, and because of the low density of bottom ash, it also helps to make lighter products, making them more cost-competitive as raw material replacements [8].

Based on the ongoing fine aggregate erosion in buildings, The building sector is being forced to reevaluate its use of industrial wastes as extra resources [9]. Bottom ash usage in the building industry has the potential to be a solution to the material disposal problem. As a result, there is a good likelihood that this bottom ash can be used as a reinforcing agent for stone columns, significantly lowering the cost of a construction project [10].

2. Methodology

For each bottom ash column, it is encapsulated with geotextile. Before pouring the bottom ash into the constructed hole at the center of kaolin sample, geotextile needs to be prepared according to the height and diameter needed. As the geotextile is done, it will be inserted into the hole constructed at the kaolin sample. Then, bottom ash was poured into the geotextile, which can avoid the leakage of bottom ash since bottom ash is granular material and possesses a coarse surface.

To determine the undrained shear strength of soft kaolin reinforced with single encapsulated bottom ash column, physical models or samples need to be prepared. Three batches with five samples from each batch were formed. A total of 15 samplers were formed and marked with a letter such as A, B, C, and others for each sample. All of the samples are reinforced with a single encapsulated bottom ash column. By using the replacement method, which used auger, the hole for bottom ash for each sample was constructed at the center of each sample with a predetermined diameter and height. To have a consistency density, the bottom ash was poured about 15 mm height above the sample into the constructed hole.

Three batches of kaolin were prepared where each batch consisted of three samples. For the first batches, the soft kaolin sample is 100 mm in height and 50 mm in diameter, while the bottom ash column is 60 mm in height and 20 mm in diameter. For the second batch, the soft kaolin sample is 100 mm in height and 50 mm in diameter, while the bottom ash column is 80 mm in height and 20 mm in diameter. Furthermore, for the last batch, the soft kaolin sample is 100 mm in height and 50 mm in diameter, while the bottom ash column is 100 mm in height and 20 mm in diameter. Finally, the UCT will be conducted to measure the strength of each sample (UCT). Figure 1 depicts the placement of the column in the centre of the sample.

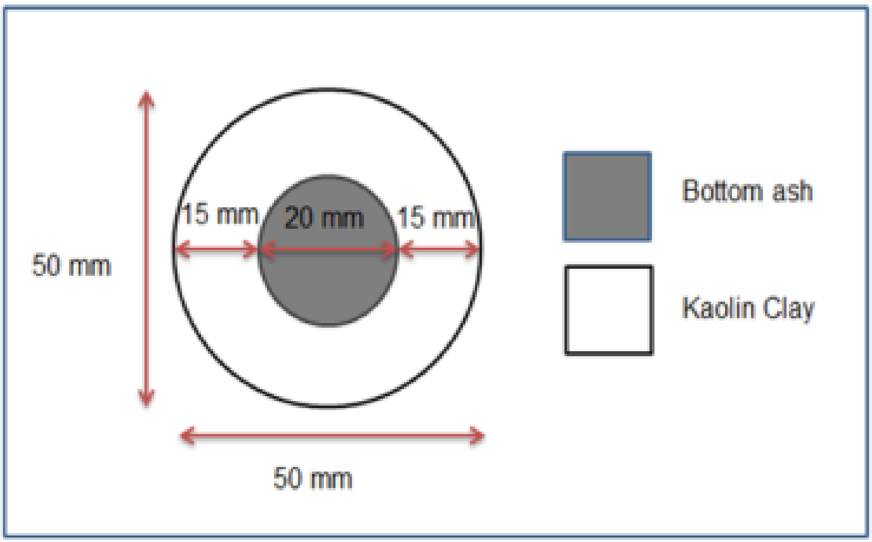

Figure 1. Installation of Column at the Centre of the Sample

3. Results and Discussion

The result of all the tests that were conducted shows that the properties of kaolin clay had the similarity as the properties of soft clay and bottom ash's characteristics shows the similarity of characteristics to those typical sand and fine gravel. Thus, there is huge potential for bottom ash to be one of the materials to be used as a substitute material for vertical granular columns or stone columns.

Some laboratory tests were carried out to determine the properties of materials used, which are bottom ash and kaolin. The laboratory tests were conducted to determine the properties of kaolin S300 included Atterberg Limit Test, Specific Gravity Test, Dry Sieve Test, Hydrometer Test, Falling Head Permeability Test, and Standard Compaction Test. Meanwhile, the laboratory tests to determine the properties of bottom ash were the Dry Sieve Test, Specific Gravity Test, Standard Compaction Test, Constant Head Permeability Test, Direct Shear Test, and Relative Density Test.

3.1. Main Materials Properties

Tables 1 and 2 present a summary of the properties of kaolin clay and bottom ash.

Table 1. Kaolin Clay Properties.

Test	Properties`	Results
Atterberg Limit	PL, w_p	26.26%
	LL, w_L	36.00%
	PI, I_p	9.74%
Specific Gravity	Specific Gravity, G_s	2.62
Compaction	Max. Dry Density, ρ_d (max)	1.55 Mg/m^3
	Opt. Moisture Content, W_{opt}	19.40%
Soil Classification	Soil Classification (AASHTO)	A-7-6^b
	Soil Classification (USCS)	ML
Permeability	Coefficient of Permeability	8.9573 x 10^{-12} m/sec

Table 2. Bottom Ash Properties.

Test	Properties`	Results
Soil Classification	Particle Size Range	2 mm to 0.063 mm
	Soil Classification (AASHTO)	A-1-a
Specific Gravity	Specific Gravity, G_s	2.33
Compaction	Max. Dry density, ρ_d (max)	0.671 Mg/m^3
	Opt. Moisture Content, W_{opt}	23.60%
Relative Density	Relative Density	98.00%
Direct Shear	Peak Cohesion	7.28 kPa
Permeability	Constant Head Permeability	5.03 x 10^{-3} m/sec

The condition of clay soil can be altered by changing the moisture content of the soil. Atterberg limit test was conducted to determine the amount of water needed to achieve a range of states of behavior, known as the liquid limit (w_L) and plastic limit (w_p) of kaolin. A liquid limit test was carried out to determine the lowest moisture content at which the soil was plastics. The test was conducted on soil in its natural state or on air-dried soil that has been remixed with water.

The specific gravity of kaolin and bottom ash was conducted by using small pycnometer method. Based on the test that was carried out, the specific gravity for kaolin is 2.62, which is in the range particle density of most soil. The specific gravity of bottom ash collected from Tanjung Bin power plant was found out to be 2.33. The major problem that causes the relatively low specific gravity is because of the low iron oxide content in the soil. Besides, the quality of bottom ash can be estimated by the value of specific gravity. Poor quality of bottom ash would show a specific gravity of as low as 1.60, attributed to the significant amount of porous and popcorn-like particles in the compositions.

Particle size analysis for kaolin was carried out by using the combination of hydrometer test and dry sieving method. A majority of the size of kaolin clay was found to be in the range of 0.2 mm to 0.001 mm. According to AASHTO, classification system, kaolin is identified as clayey soil (Group A-7-6^b). Particle size analysis for bottom ash was conducted by using sieve analysis in accordance with dry sieving method. A significant fraction of bottom ash sizes was found to be in the range between 10 mm and 0.063 mm, which falls in the range of fine gravel to fine sand sizes. Unified Soil Classification System (USCS) stated that the soil is classified as well-graded sand (SW), while according to the ASSHTO classification system; bottom ash is characterized in A-1 group and classified as A-1-a, which contain stone fragments with a well-graded binder of fine material.

The maximum dry density, ρ_d(max) for kaolin is 1.55 Mg/m^3 (15.21 kN/m^3) while for bottom ash is 0.671 Mg/m^3 (6.58 kN/m^3) with optimum moisture content, w_{opt} of 20% and 23.60% respectively. The result that being produce in direct shear test of Tanjung Bin bottom ash are the internal friction angle were 38.83° and cohesion were 7.28 kPa.

The value of permeability coefficient of kaolin obtained by the falling head permeability test was 8.9573 x 10^{-12} m/sec at a maximum dry density of 1.55 Mg/m^3. The permeability coefficient of bottom ash was measured by a constant head test and resulted the value of permeability 5.03 x 10-3 m/sec. Based on the measured value shows that a medium degree of permeability of bottom ash indicating good drainage characteristics and generally corresponding to clean sands.

3.2. Shear Strength

The UCT was conducted to determine the strength of soft kaolin clay reinforced with an encapsulated bottom ash column (UCT). A set of samples with a 16 percent area replacement ratio was prepared. Three (3) batches of samples were prepared with different heights of encapsulated bottom ash column, which are 60mm, 80mm, and 100mm. Each batch of samples has a different height penetration ratio, 0.6, 0.80, and 1.00. The strength improvement of the samples is illustrated in Table 3 below.

Table 3. Improvement of Shear Strength.

Sample	Column Diameter (mm)	Area Penetration Ratio, Ac/As (%)	Column Number	Height of Column (mm)	Height of Penetration Ratio, Hc/Hs (%)	Average Shear Strength (kPa)	Percentage of Improvement (%)
Control	0	0	0	0	0	8.83	-
Batch 1	20	16.0	1	60	60	11.64	31.82
Batch 2	20	16.0	1	80	80	13.67	54.81
Batch 3	20	16.0	1	100	100	14.26	61.49

3.2.1. Column Penetration Ratio Effect

The graph demonstrates the increase in shear strength at penetration ratio for a singular encapsulated bottom ash column. The graph depicts the sample-encased bottom ash column at 0, 0.6, 0.8, and 1.0 for a 16 percent area penetration ratio. As the penetration ratio of the bottom ash column increases, the percentage of increment becomes significant.

The reason for the increase in increment is because a portion of the soft soil has been replaced by stiffer material, which is bottom ash. It demonstrates that the penetration ratio of the bottom ash column influences shear strength enhancement. Figure 2 depicts a graph of shear strength vs penetration ratio height.

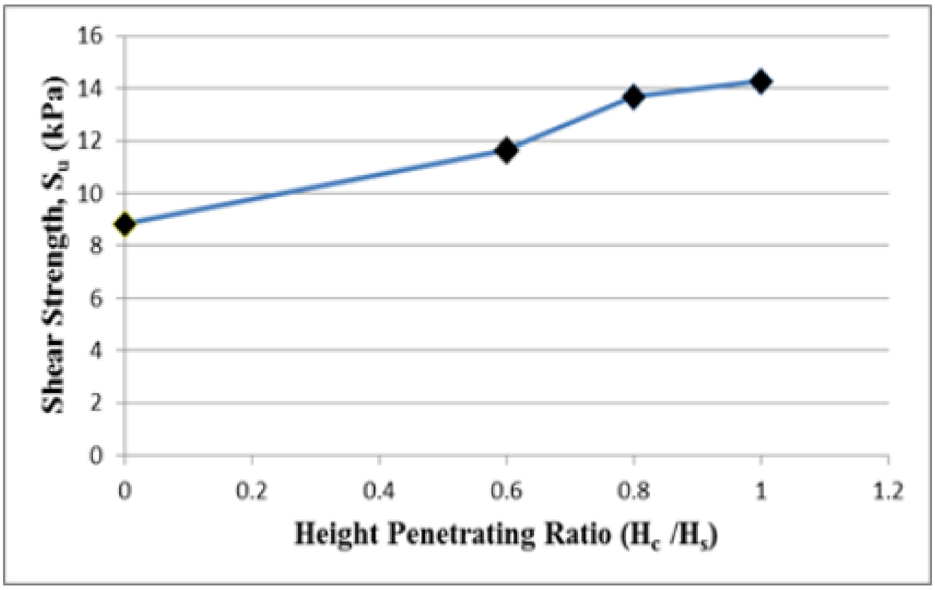

Figure 2. Shear Strength versus Height of Penetration Ratio

3.2.2. Height over Diameter of Column Effect

The graph indicates that the height over column diameter ratio has an effect on the strength, with the strength increasing as the height over column diameter ratio increases. It demonstrates that the increment in strength is also affected by the column's height over diameter.

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The reason for the increase in increment is because a section of soft soil has been replaced by stronger material, which is bottom ash. We can assume that the growing shear strength is likewise dependent on the column's height over diameter. Figure 3 depicts a graph of shear strength vs. column height over diameter.

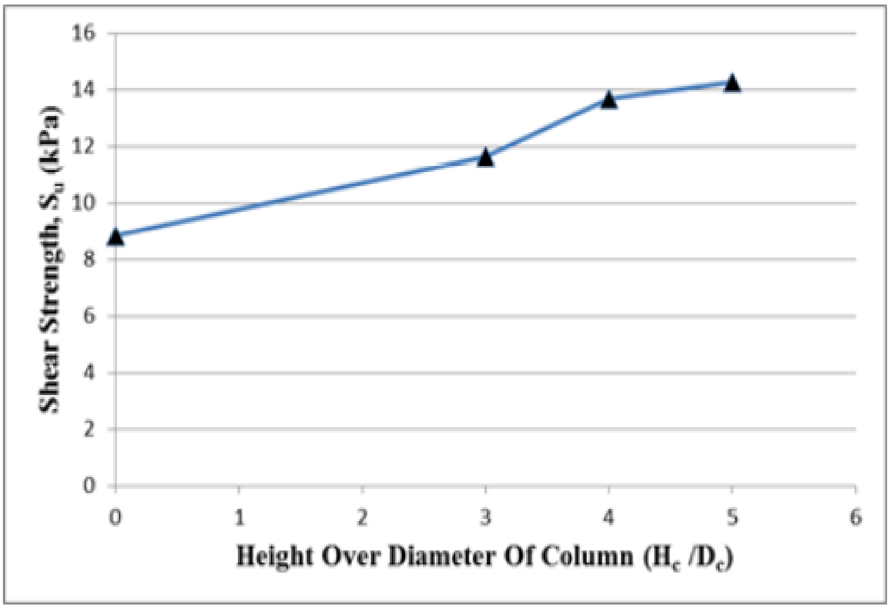

Figure 3. Strength versus Column Height over Diameter

3.2.3. Volume Penetration Ratio Effect

The graph illustrates that the strength of the sample grows as the volume of the enclosed bottom ash column increases. This demonstrates that the volume of the column influences the enhancement of sample shear strength. This is due to a section of soft soil being replaced by stronger material, which is bottom ash. Figure 4 depicts the strength versus volume penetration ratio graph.

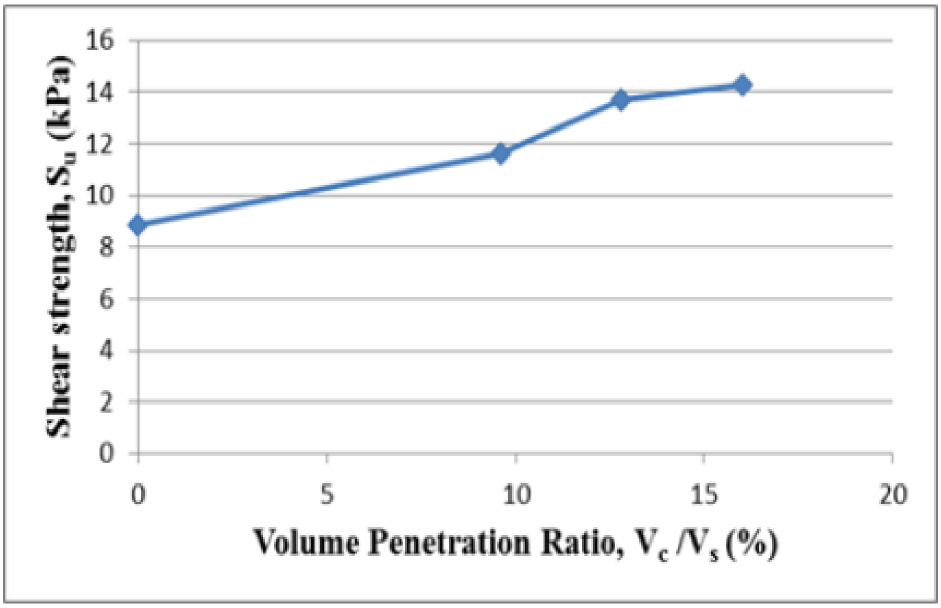

Figure 4. Strength vs Volume penetration Ratio

4. Conclusions

Based on the laboratory test findings shown in Table 1, kaolin may be classified as ML. Based on the water absorption and plastic viscosity, it has a low elasticity value of 26.26 percent and 9.74 percent, respectively. The soft kaolin clay was categorized as well graded, with grain sizes ranging from clay to fine silt.

The majority of the kaolin clay size was discovered to be in the range of 0.2 mm to 0.001 mm. Kaolin is classified as clayey soil under the AASHTO classification system (Group A-7-6b). Bottom ash has properties that are similar to sand. According to the ASSHTO categorization system, bottom ash is classified as A-1-a, which includes stone fragments, gravel, and sand.

Bottom ash has an internal friction angle of 38.83, which is substantially higher than normal fine sand, since the shear strength of bottom ash was supplied by expressiveness and coarse surface characteristics, which generate a high degree of interlocking and so prevent inter-particle sliding. The bottom ash column is thus appropriate for use as a fine aggregate alternative since it has qualities comparable to sand.

The presence of a bottom ash column, as well as the improvement in shear strength, has greatly boosted the strength properties of kaolin. The mean shear stress of each specimen encapsulated bottom ash column at 0, 0.6, 0.8, and 1.0 of height increases as the height and volume increase. As the penetration ratio of the bottom ash column increases, the percentage of increment becomes significant.

The reason for the increase in increment is because a portion of the soft soil has been replaced by stiffer material, which is bottom ash. It demonstrates that the penetration ratio of the bottom ash column influences shear strength enhancement. The stone column technique is a highly effective means of enhancing soil strength parameters as in load-carrying capacity and decreasing consolidation settlement.

Furthermore, the use of bottom ash in the construction industry has the potential to be a solution to the material disposal problem. As a result, there is a considerable chance of using this bottom ash as a replacement material for stone columns. This significantly reduces the budget of the project.

Acknowledgments

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