International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

The Influence of Bottom Ash Column in the Geotechnical Properties Enhancement of Soft Clay Soil

Ng Jun Shen[1], Muzamir Hasan[2], Nur Amina Azmyra Hashim[3]

[1]Researcher, Department of Civil Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah
[2]Associate Professor, Department of Civil Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah
[3]Researcher, Department of Civil Engineering, Universiti Malaysia Pahang Al-Sultan Abdullah

Abstract
The utilization of bottom ash in ground improvement studies can cut down the quantity of generated waste which is in response to environmental conservation and enhancing the soil properties. The bottom ash which plays the role of replacing the coarse aggregate like sand and gravel in upgrading the behaviour of soft clay soil can fulfill the sustainability concept in construction. For construction purposes, the soil and ground improvement activities are necessary to carry out by using the relevant techniques, including the vibro-replacement method. This method was applied which suits the limitation of this study as it was executed in the laboratory for the preparation of the bottom ash column. The properties examination of kaolin clay and bottom ash were first studied through its particle size, specific gravity, liquid and plastic limit, and compaction. The following procedure was about the column preparation process, where the column diameter was set to be constant at 20 mm throughout the study. The execution of the Unconfined Compression Test (UCT) on the Bottom Ash Column has shown its impact on the undrained shear strength upgrade and it was focused on the height of the bottom ash column built beneath the kaolin clay at 60mm, 80mm, and 100 mm. As observed from the trend, the height of the bottom ash column shows a direct proportional relationship by the undrained shear strength, ranging from 11.64% - 14.26% by using the control sample (with no bottom ash reinforcement) as reference. Conclusively, the use of bottom ash subsides the disposal waste and in no time provides support to the shear strength of soft clay soil which is sustainable and applicable.

Keywords: Expansive clay, Bottom ash, Ground improvement

1. INTRODUCTION

In a modernized and civilized era, construction has played an important role in modernizing an area to an industrialized and technological zone which provides convenience to the human, contributing to the Gross Domestic Product (GDP) of a country. Due to the increasing population as the country progresses, sustainability plays an important role in conserving the environment so that the balance of nature is always maintained. Recently, concerning sustainable goals due to the unresolved global environmental issues, all the economy activities around the world have started to practice the ESG (Environmental (E), Social (S), and Governance(G)) concepts as a response to the increasing severe sustainable development problems (Li et al. 2021). From this concept, the entrepreneurs can optimize the impact on the environmental, providing a healthier social development by practicing a good governance system in the company. As the development of an area that requires the clearing of forest regardless of the conditions of the land, the ESG concept minimizes the loss of habitat of flora and fauna by conserving and preserving them according to the respective Standard Operating Procedure (SOP) that varies across the countries. If a place is strategic in terms of its location for the country's economic growth, the government of the country will need to develop the land by recruiting specialists to make the land suitable to be used for construction purposes especially if the land is filled with abundant kaolin materials.

Kaolinite better known as kaolin or China Clay as it was named after Gaoling or High Hill in the Town of Jingle, located in Jiangxi, China has the general chemical formula $Al_2Si_2O_5(OH)_4$. This material mainly consists of white or nearly white minerals when it is beneficiated or fired under a certain temperature (Pruett, 2016). Besides, it is commonly available in powder form, which can be seen through bear eyes and they are fine-type materials. The category of kaolin or clay is generally classified through its engineering properties with their weakness as they are poor in terms of bearing strength, coefficient of compressibility, dispersion of soil particles, erosion issues as well as susceptible to structure crisis if the soil was used for construction purposes (Hilal and Hadzima-Nyarko, 2021; Rezaei-Hosseinabadi et al. 2022). Referring to their properties, a great concern to use land with an abundance of kaolin has always been considered as it may lead to the catastrophic impact and the cost of soil treatment that makes the soil condition applicable for the building placement on top of it. Thus, soil and ground improvement techniques have been modified from time to time by previous researchers to provide the best materials to rectify the poor properties of soil by upgrading the shear strength of soft soil (Zaini and Hasan, 2023). Similar to many developing countries around the world, Malaysia has been actively developing by holding many huge projects to transform the country into a first-world country. For example, the currently ongoing infrastructure project, East Coast Rail Line (ECRL) project is planning to be built covering from Selangor to Kelantan and thus, the geotechnical works which include the earthworks and soil treatment are required to be carried out before the construction project begins (Hasan et al. 2015; Aljanbi et al. 2013).

As for laboratory scale tests, many researchers have utilized different types of recycling materials for the substitution of coarse-type materials such as Polypropylene (PP) plastic which proved the strength of the soft clay soil can be enhanced (Hasan et al. 2015). Moreover, other recycling materials like the residual by-product of coal burning that is capable of generating electricity which are fly ash and bottom ash (Marto et al. 2011), have also been used in the modification of road base and sub-base, backfill material, concrete aggregate, drainage media as well as abrasive material (Ramme and Tharaniyil, 2013). Bottom ash is commonly used in civil engineering research due to its particle size distribution which is similar to the natural aggregate, river sand. Behaving like coarse-aggregate type materials, it has the potential to replace a certain amount of sand or gravel which is a non-renewable material that can build a higher greenery index of building.

2. METHODOLOGY

The current chapter is about the entire laboratory work conducted to achieve the objectives of this research. The research was primarily conducted by selecting the required materials and the ground improvement techniques, which are kaolin clay S300 and bottom ash using the vibro-replacement technique, followed by the execution of laboratory works by complying with the American Society Testing Materials (ASTM) and British Standards (BS) which has split into two parts, the general properties of materials and the shear strength parameters analysis.

2.1 SELECTION OF MATERIALS

In this research, the primary material which is kaolin clay S300 was purchased from Kaolin (M) Sdn. Bhd which is located in Selangor. The reason for selecting this material as it is cheap and easily available. From its texture and chemical formula, this material suits the research objective which can easily break and mix when the material is wet (mixed with optimum water volume). Besides, kaolin clay S300 is a hydrophilic material as shown in Figure 1, tends to form a slurry product that is capable of producing a homogeneous bottom ash column during the column preparation process. From the perspective of properties, kaolin clay S300 which behaves like silty clay has drawn the attention of the authors to use this material. The secondary material which is bottom ash as shown in Figure 2 was made available from Tanjong coal power plant which is located in Johor, a company owned by Malakoff Corporation Berhad. The main reason for the bottom selection by the authors is due to the material complies with the concept of sustainability as it is a by-product from the coal plant, which can reduce environment pollution and optimize the usage of recycling products.

Figure 1. Kaolin Clay S300 (Zaini et al. 2021)

Table 1. Properties of Kaolin Clay S300 (Damoerin et al. 2015)

No.	Physical parameters	Value
1	Colour	White
2	Natural water content (%)	1.58
3	Specific gravity	2.59
4	Atterberg limits:	
	• Liquid limit, LL (%)	77.93
	• Plastic limit, PL (%)	39.10
	• Plastic Index, PI (%)	38.83
5	Sieve analysis:	
	• Sand (%)	0
	• Silt (%)	47
	• Clay (%)	53

Figure 2. Bottom Ash from Tanjong Coal Plant (Zaini et al. 2021)

2.2 EXPERIMENTAL WORKS

The entire process of the research is depicted in Figure 3. As mentioned previously, the laboratory works were executed in two parts, the laboratory works that demonstrated on the left-hand side of the flow chart were to obtain the properties of materials while the right-hand side was about the analysis of shear strength parameters. To classify them into more detailed data, Table 2 presents the related works based on the respective objectives and its standards used during the implementation of works.

To determine the distribution of particle size of bottom ash, Sieve Analysis was conducted with the use of 9 different sieve sizes, and the majority of particle size retained on that specific sieve was used as the replacement material based on the standard as stated in Table 2. A hydrometer test was conducted for kaolin clay S300 as this material passes through the 0.063 mm sieve size or more than half portion of the particles are finer than 63 µm. The primary principle of this test is based on Stoke's law by manipulating the velocity of the particles. Other than particle size, the Atterberg limit that consists of the liquid and plastic limit tests were conducted for kaolin clay S300. Besides, the specific gravity for both materials was also analyzed using a small pycnometer. The test was conducted and computed using the fraction parameter of soil as the fundamental to determine the specific gravity value.

The analysis of proctor parameters is linked to the Standard Compaction test and it was for kaolin clay S300. From this test, the average amount of water content was obtained by the dry density of the substance, producing the Standard Compaction curve. Moreover, the raw data of bottom ash in terms of its cohesion and friction angle were obtained from the Direct Shear test by plotting the graph of maximum shear stress versus normal stress. One of the parameters, which is the minimum and maximum dry density of bottom ash was obtained from the Relative Density test, and these values were used to interpret the value of in-situ density. The availability of the materials was also analyzed based on their permeability, where the less permeable material, kaolin clay S300 was measured using the Falling Head test while bottom ash behaved like coarse-type material was measured by the Constant Head test.

Figure 3. Flowchart of the Entire Research

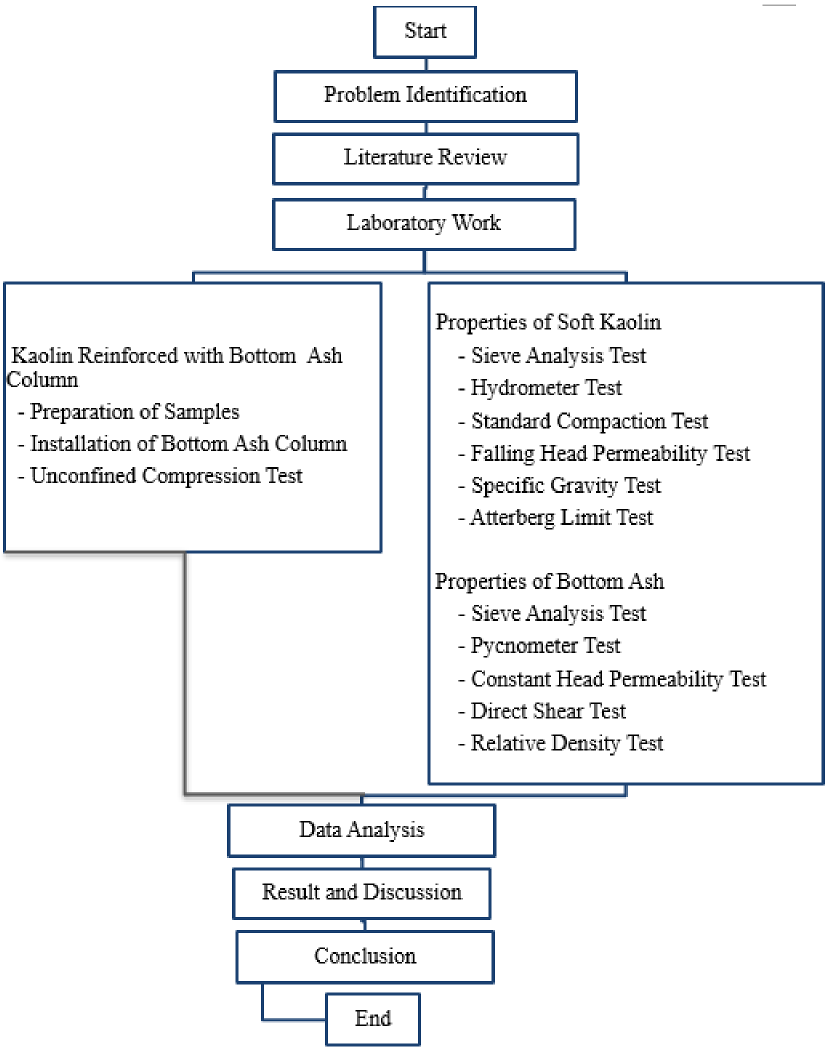


Table 2. Relevant Laboratory Works and Its Standard

Objective	Experiment	Standard
1st – Determination of engineering properties of kaolin clay S300 and bottom ash	Atterberg limit	
	✓ Liquid limit	BS 1377: Part 2: 1990: 4.3
	✓ Plastic limit	BS 1377: Part 2: 1990: 5.3
	Pycnometer	BS 1377: Part 2: 1990: 9.6
	Sieve analysis	BS 1377: Part 2: 1990: 9.6
	Hydrometer	BS 1377: Part 2: 1990: 8.3
	Relative density	ASTM D 4052
	Standard compaction	BS 1377: Part 2: 1990: 3.3
	Constant head	ASTM D 2434
	Falling head	ASTM D 2434
	Direct shear test	BS 1377: Part 7: 1990: 4
2nd – Determination of shear strength parameter by reinforcing the kaolin clay with	Unconfined compression	ASTM D 2166

bottom ash column

Before conducting the UCT, the material preparation was executed as the first stage by using about 280g of kaolin clay S300 to construct the control sample (with no bottom ash reinforcement) with an optimum moisture content (determined from the standard compaction curve) of about 19.40% in a properly-designed mould with the dimensions of 50 mm diameter and 100 mm height in Figure 4(a). The process was followed by the drilling process by a 20 mm diameter drilling bit and pouring process of bottom ash through the raining method as demonstrated in Figure 4(b) to the respective height using the prepared kaolin sample in the first stage. Each column design includes the control sample mainly the difference in column height, 5 samples were prepared to obtain the best and most accurate value by following the design arrangement in Figure 5(c). After completing all the processes as mentioned in Figure 4 (a), (b), and (c), the UCT was only executed to test the stiffness of the column as shown in Figure 5.

Figure 4. Bottom Ash Column Preparation Process (a) Design Arrangement of Column (b) Properly-Designed Mould (c) Hole-Drilling Process

(a) Design arrangement of column (b) Properly-designed mould (c) Hole-drilling process

Figure 5. The Specimen was Tested under the Machine

As part of the analysis of shear strength parameters, the ratios that are influencing the performance of the bottom ash column are listed in Table 3, which includes the Height Penetrating Ratio (H_c/H_s), Column Height to Column Diameter ratio (H_c/D_c) as well the Volume Replacement Ratio (V_c/V_s). The design of the column is denoted by the alphabet of "S", showing that it is a singly-built column 20 denotes the column diameter, and 60 or 80 or 100 denotes the height of the column.

Table 3. Column Parameter for Bottom Ash Column

No.	No. of Column	Design	Diameter	Height (mm)	H_c/H_s	H_c/D_c	V_c/V_s
1	1	Control	-	100	-	-	-
2	1	S2060	20	60	0.6	3.0	9.60
3	1	S2080		80	0.8	4.0	12.80
4	1	S20100		100	1.0	5.0	16.00

3. FINDINGS AND INTERPRETATION

This chapter splits the discussion into three parts, where the first part is about the general behavior and properties of the materials used in the study, and the second part is the discussion about the performance of the bottom ash column based on the relationship between column ratios and shear strength parameters, and the last part is the correlation of the column ratio to the shear strength improvement of the bottom ash column by presenting the regression equations.

3.1 PHYSICAL AND MECHANICAL PROPERTIES OF KAOLIN CLAY S300 AND BOTTOM ASH

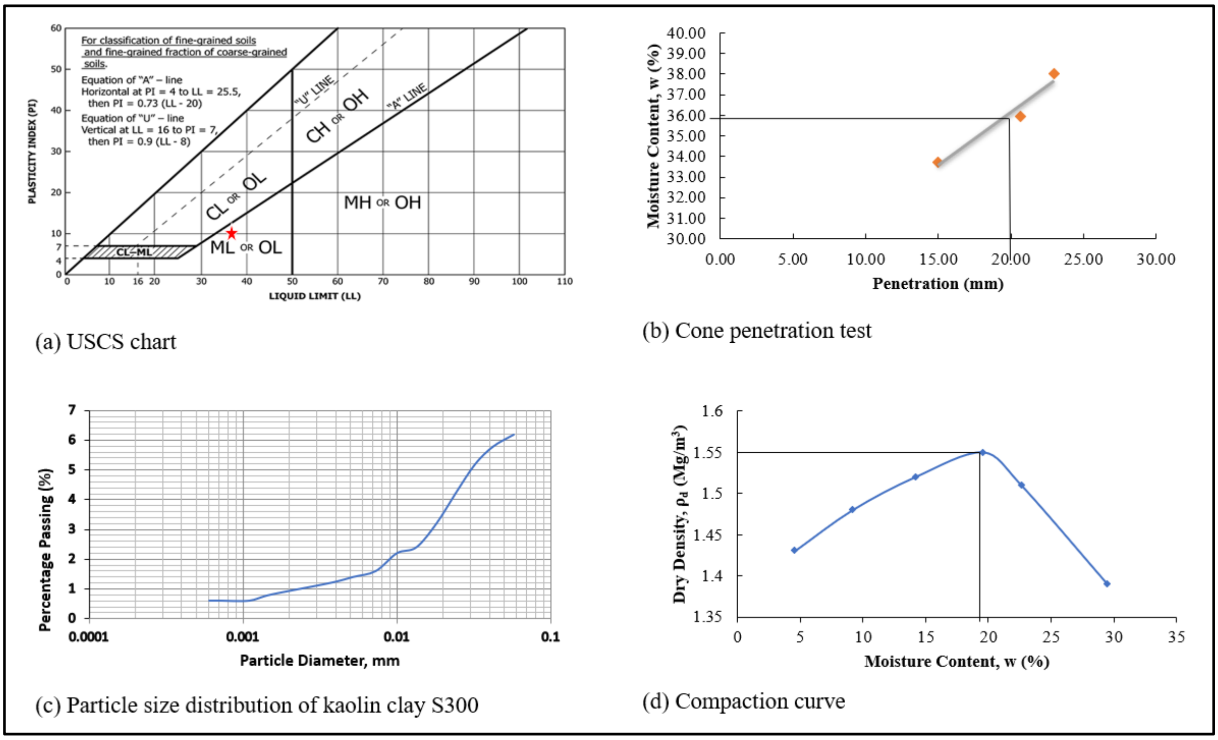
As referred to in Figure 3, the material properties of kaolin clay S300 are presented in Table 4. Based on the soil classification, it shows A-7-6 from AASHTO, signifying that the soil is poor clayey soil while the USCS shows that it is under the ML category or clayey fine sand as shown in Figure 6(a). Based on the previous findings, the kaolin clay S300 was also classified as ML based on the USCS (Hasan et al. 2015), mentioning that it is a slurry product when water is present. The above result was determined by associating the result from the Atterberg limit test as shown in Figure 6 (b). Kaolin clay S300 is a well-graded particle based on Figure 6(c), where a majority of particle size lies within 0.2 mm to 0.001 mm. From the standard compaction curve in Figure 6 (d), an approximate value of 19.40% was determined by the value of maximum dry density, 1.55Mg/m3, and these values were used as the reference of the volume of water during the column preparation process. The coefficient of permeability shows that this material is susceptible to water accumulation as the value shows that it is a less permeable material, obtaining the value of approximately 8.96 x 10^{-12} m/s.

Table 4. Kaolin Clay S300 Properties

TEST	PROPERTIES	RESULTS
Atterberg Limit Test	Plastic Limit, w_p	26.26 %

	Liquid Limit, w_L	36 %
	Plastic Index, I_p	9.74 %
Pycnometer Test	Specific Gravity, G_s	2.62 Mg/m^3
Standard Compaction Test	Maximum Dry Density, $\rho_{d(max)}$	1.55 Mg/m^3
	Optimum Moisture Content, W_{opt}	19.40 %
Soil Classification	Soil Classification (AASHTO)	A-7-6
	Soil Classification (USCS)	ML
Falling Head Permeability Test	Coefficient of Permeability	8.9573 x 10^{-12} m/s

Figure 6. Kaolin clay S300 properties (a) USCS chart (b) Cone Penetration Test (c) Particle Size Distribution of Kaolin Clay S300 (d) Compaction Curve



(a) USCS chart

(b) Cone penetration test

(c) Particle size distribution of kaolin clay S300

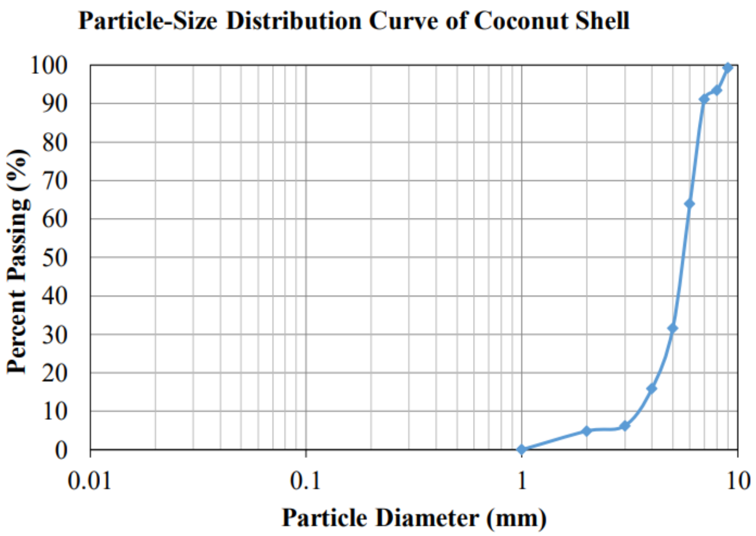
(d) Compaction curve

As for bottom ash, the properties were concluded in Table 5 for the respective parameters. From the sieve analysis test, the particle size was ranging between 2 mm to 0.063 mm in Figure 7, which behaves like river sand as mentioned in Chapter 1. The soil classification of bottom ash mentions it behaves like sand-type material is further proven by using AASHTO, A-1-a shows that it has the stone fragment particle size. The specific gravity of the bottom ash obtained is 2.33, which is similar to the previous result, obtaining 2.23 (Abuelgasim et al. 2020). The relative density results prove that the void ratio of the bottom ash is low, by getting the 98% or 0.668Mg/m3 of in-situ density. Referring to its coefficient of permeability of bottom ash, 5.03 x 10^{-3} m/s it can discharge and resolve the water accumulation issue by providing additional drainage. The direct shear test results also show that the bottom ash is capable of withstanding higher axial stress with the value of 7.28kPa from its peak cohesion value.

Table 5. 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 Test	Specific Gravity, G_s	2.33
Relative Density Test	Minimum Dry Density, $\rho_{d(min)}$	0.549 Mg/m^3
	Maximum Dry Density, $\rho_{d(max)}$	0.671 Mg/m^3
	In-situ density	98%
Direct Shear Test	Peak Cohesion	7.28 kPa
	Angle of Shearing Resistance	38.83°
Permeability Test	Constant Head Permeability	5.03 x 10^{-3} m/sec

Figure 7. Particle Size Distribution Curve of Bottom Ash



3.2 UNCONFINED COMPRESSIVE STRENGTH OF KAOLIN CLAY S300 AFTER THE REINFORCEMENT OF BOTTOM ASH COLUMN

This sub-chapter discusses the result from UCT, mainly the shear strength parameters concerning the column parameters. The shear strength value is represented by S_u and the shear strength improvement value is denoted by ΔS_u. The demonstrated value of S_u in Table 6 is the average value obtained from five identical specimens, and the value is used for the calculation of ΔS_u by using the shear strength value of the control sample as the reference of calculation. From Table 6, it is noticed that the value of shear strength has the direct proportional relationship in accordance to all the column ratio. The highest value of improvement is recorded when the column height is at 100 mm, or consider the largest replaced volume of bottom ash. Therefore, the critical column suggested in this study is 1.0.

Table 6. Results from UCT

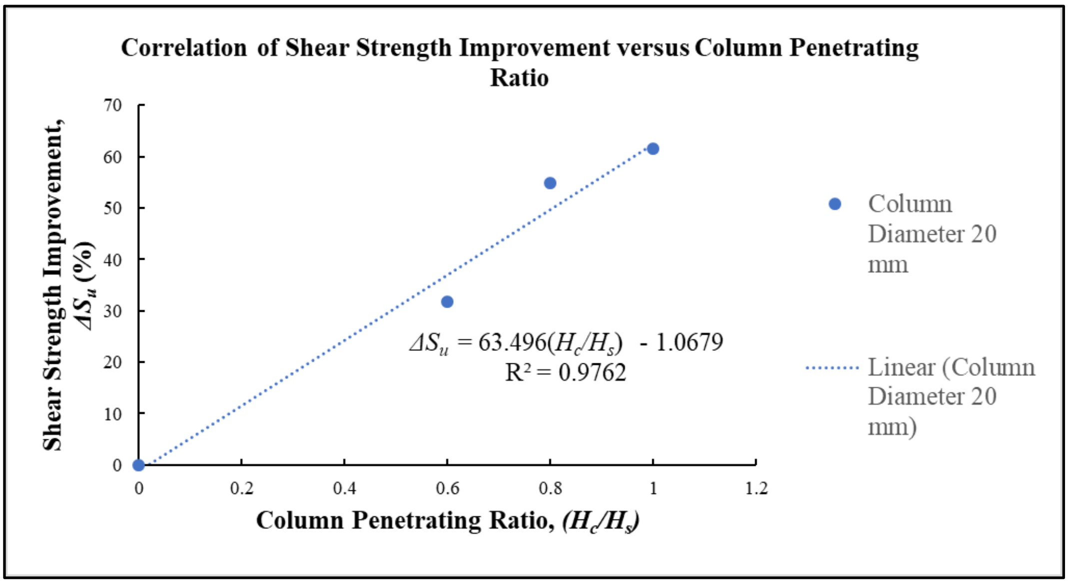
Design	Diameter	Height (mm)	H_c/H_s	H_c/D_c	V_c/V_s	S_u	ΔS_u
Control	-	100	-	-	-	8.83	-
S2060	20	60	0.6	3.0	0.096	11.64	31.82
S2080		80	0.8	4.0	0.128	13.67	54.81
S20100		100	1.0	5.0	0.160	14.26	61.49

3.3 CORRELATION OF SHEAR STRENGTH IMPROVEMENT VERSUS COLUMN PENETRATING RATIO

From Table 6, the range of H_c/H_s ranges from 0.6 to 1.0, and the shear strength improvement rate is from 31.82% to 61.49%, the value almost increased twice as compared between the lowest and the highest value of improvement. The largest improvement was recorded when the ratio is 1.0, recorded at 61.49%, followed by 54.81% when the column height is at 80 mm or 0.8. The least value of improvement is 31.82% when the bottom ash column height is the shortest, only 60 mm. From Figure 8, it shows that it is a linear graph with the regression equation of $R^2 = 0.9762$ and is presented in Equation (1).

$$\Delta Su = 63.496((H_c/H_s) - 1.0679 \quad (1)$$

Figure 8. Correlation of Shear Strength Improvement versus Column Penetrating Ratio

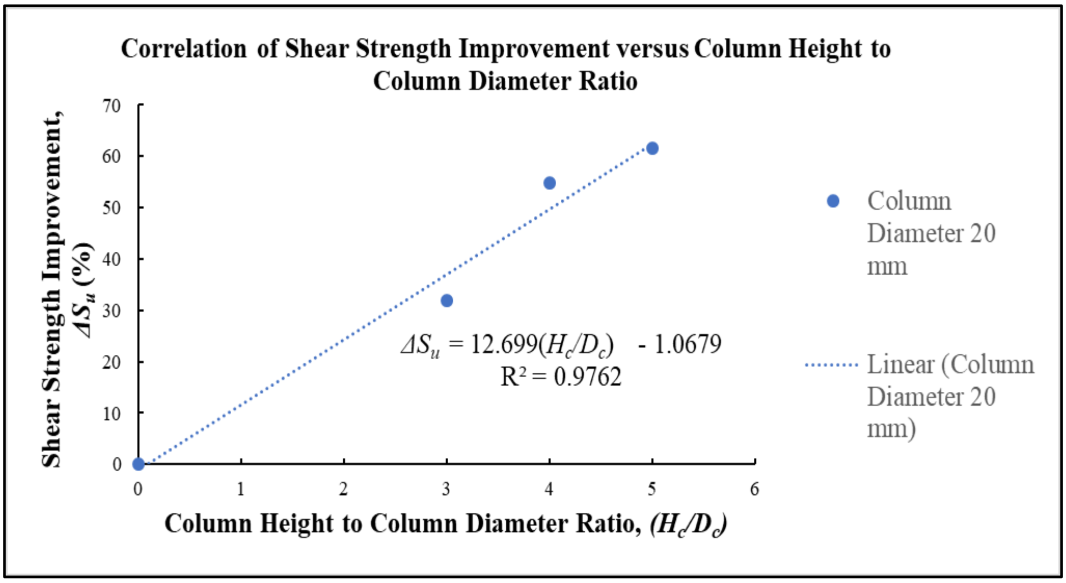


3.4 CORRELATION OF SHEAR STRENGTH IMPROVEMENT VERSUS COLUMN HEIGHT TO COLUMN DIAMETER RATIO

This sub-topic discusses how the column height to the column diameter ratio affects the performance of the bottom ash column. Based on Table 6, the highest value of Hc/Dc, 5.0 shows the largest value of improvement. This value is supported by previous researchers who mentioned that the optimum value of this ratio should be within 4 – 6 times (Hasan et al. 2018), where in this study there are two values from the overall in this category. From the regression value, the value is more than 0.5 proving that this group of results is accurate and the previous researcher has predicted the correct range of values for this ratio. From Figure 9, the R2 value is equal to 0.9762 and the Equation (2) presents the correlation function.

$$\Delta Su = 12.699(H_c/D_c) - 1.0679 \quad (2)$$

Figure 9. Correlation of Shear Strength Improvement versus Column Height to Column Diameter Ratio

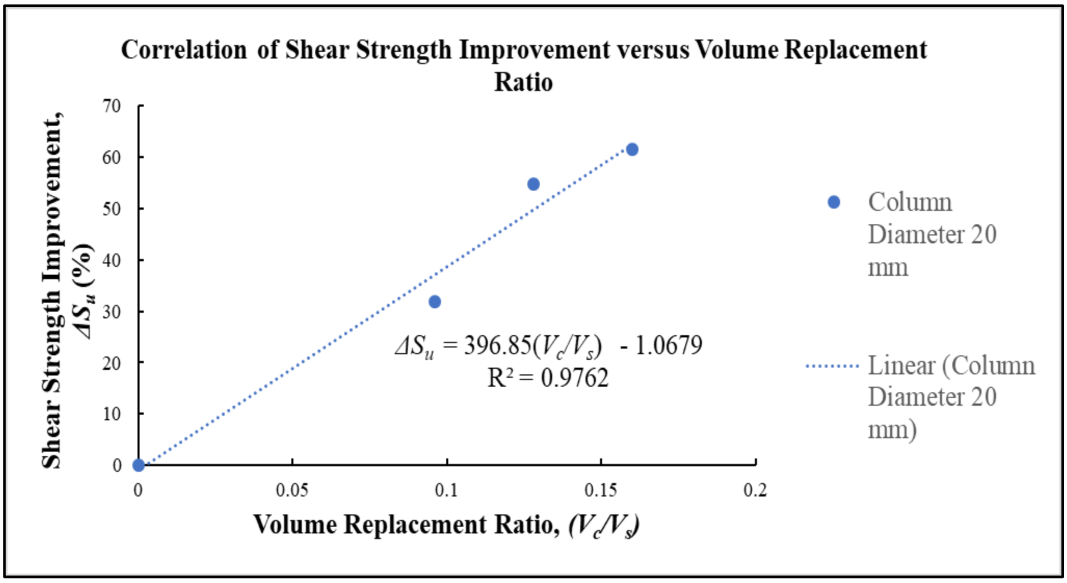


3.5 CORRELATION OF SHEAR STRENGTH IMPROVEMENT VERSUS VOLUME REPLACEMENT RATIO

The volume replacement indicates the quantity of kaolin that is being replaced with the foreign material, bottom ash. Referring to Table 6, the larger the amount of bottom ash in the kaolin clay, the larger the improvement rate of kaolin clay S300. When the replacement ratio comes to 0.16, the rate of improvement recorded is the highest, 61.49%. Based on Figure 10, The correlation equation is clearly shown in Equation (3) with the R2 value equal to 0.9857.

$$\Delta Su = 396.85(V_c/V_s) - 1.0679 \quad (3)$$

Figure 10. Correlation of Shear Strength Improvement versus Volume Replacement Ratio



4. CONCLUSION

This chapter concludes all the important findings of this research using the bottom ash as the replacement material of coarse-type materials such as sand. The relevant geotechnical works were executed by following all the international standards and the summarized outputs are as follows;

1. The kaolin clay is naturally soft, which is not suitable for building any structure unless soil treatment and ground improvement works are carried it. Based on the properties as demonstrated in Table 4, it provides a clear understanding of kaolin clay S300 to the readers as this type of soil is susceptible to the water accumulation problem due to low permeability.
2. By installing the reinforcement which is bottom ash, the strength of the soil has been upgraded through the respective tests. The column ratios which play a crucial part have affected the performance of the bottom ash column. The general trend of the performance suggests that they are a directly proportional relationship, proving that the larger amount of bottom ash can enhance the soil to a higher value of shear strength.
3. By using the correlation technique as shown in Figures 8, 9, and 10, it shows that the results from UCT are accurate as the regression value, R^2 are showing more than the average benchmark. 0.5.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) for assisting and providing financial support through the Master Research Scheme (MRS) and Post Graduate Research Scheme (PGRS). PGRS2303122, respectively. The cooperation given by all parties involved in this research is greatly acknowledged.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in the paper

REFERENCE

1. Abuelgasim, R., Rashid, A. S. A., Bouassida, M., Shien, N., & Abdullah, M. H. (2020, September). Geotechnical characteristics of Tanjung Bin coal bottom ash. In *IOP Conference Series: Materials Science and Engineering* (Vol. 932, No. 1, p. 012055). IOP Publishing.
2. Aljanabi, Q. A., Chik, Z. A. M. R. I., & Kasa, A. N. U. A. R. (2013). Construction of a new highway embankment on the soft clay soil treatment by stone columns in Malaysia. Journal of Engineering Science and Technology, 8(4), 448-456.
3. Damoerin, D., Prakoso, W. A., & Utami, Y. (2015). Improving shear strength of clay by usingcement column reinforcement under consolidated undrained test. International Journal ofTechnology, 6(4), 709–717. https://doi.org/10.14716/ijtech.v6i4.1206
4. Hasan, M., Wan, J. W. J., Wong, S. C. and Hyodo, M. (2018). The undrained shear strength of soft clay reinforced with group encapsulated lime bottom ash columns, International Journal of GEOMATE, 14(46). https://doi.org/10.21660/2018.46.45208
5. Hasan, M., Yusuf, N., & Kassim, A. M. H. (2015). Strength of Soft Clay Reinforced with Group Crushed Polypropylene (PP). Electronic Journal of Geotechnical Engineering 20(22) 12291 – 12308.
6. Hasan, M., Yusuf, N., & Kassim, A. M. H. (2015). Strength of Soft Clay Reinforced with Group Crushed Polypropylene (PP). Electronic Journal of Geotechnical Engineering 20(22) 12291 – 12308.
7. Hilal, N., & Hadzima-Nyarko, M. (2021). Improvement of eco-efficient self-compacting concrete manufacture by recycling high quantity of waste materials. *Environmental Science and Pollution Research*, *28*, 53282-53297. https://doi.org/10.1007/s11356-021-14222-9
8. Li, T. T., Wang, K., Sueyoshi, T., & Wang, D. D. (2021). ESG: Research progress and future prospects. *Sustainability*, *13*(21), 11663.
9. Marto, A., Awang, A. R., and Makhtar, A. M. (2011). Compaction Characteristics and Permeability of Tanjung Bin Coal Ash Mixtures. International Conference on Environment Science and Engineering IPCBEE vol.8 (2011) © (2011) IACSIT Press, Singapore, p. 134-137.
10. Pruett, R. J. (2016). Kaolin deposits and their uses: Northern Brazil and Georgia, USA.Applied Clay Science, 131, 3–13. https://doi.org/10.1016/j.clay.2016.01.048
11. Ramme, B. W., and Tharaniyil, M. P. (2013). Coal combustion products utilization handbook (3rd edition). Milwaukee, WI: We Energies.
12. Rezaei-Hosseinabadi, M. J., Bayat, M., Nadi, B., & Rahimi, A. (2022). Sustainable utilisation of steel slag as granular column for ground improvement in geotechnical projects. *Case Studies in Construction Materials*, *17*, e01333. https://doi.org/10.1016/j.cscm.2022.e01333
13. Zaini, M. S. I., & Hasan, M. (2023). Effect of Optimum Utilization of Silica Fume and Lime On the Stabilization of Problematic Soils. International Journal of Integrated Engineering, 15(1), 352–366. Retrieved from https://penerbit.uthm.edu.my/ojs/index.php/ijie/article/view/9573
14. Zaini, M. S. I., Hasan, M., Sin Yie, L., Masri, K. A., Putra Jaya, R., Hyodo, M., & Winter, M. J. (2021). The Effect of utilizing silica fume and eggshell ash on the geotechnical properties of soft kaolin clay. Jurnal Teknologi, 84(1), 159-170. https://doi.org/10.11113/jurnalteknologi.v84.17115|