IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Compressibility behavior of marine clay treated by combination of coal ash and cement

To cite this article: F Pakir *et al* 2024 *IOP Conf. Ser.: Earth Environ. Sci.* **1347** 012066

Compressibility behavior of marine clay treated by combination of coal ash and cement

F Pakir[1,2*] , N A Ismail[1], N Z M Yunos[3] , N Jamaludin[4] , M K A Talib[1,2] , M F M Dan[2] and A Madun[2]

[1] Civil Engineering Department, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia
[2] Research Centre for Soft Soil, Institute for Integrated Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia
[3] Geotechnics & Transportation Department, Faculty of Engineering, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia
[4] Faculty of Engineering, Built Environment, and Information Technology, Universiti MAHSA, Selangor, Malaysia
*Corresponding author: faizalp@uthm.edu.my

Abstract. In the geotechnical field, any soft ground area that has construction on it will face a major challenge. A lot of engineering problems could arise either during or after the construction phase due to low shear strength and high compressibility of this soil in the form of excessive settlement, slope instability or bearing capacity failure. The real challenge with marine clay is stability and settlement when construction takes place. To solve this problem, study of compressibility of stabilized marine clay will be performed. The soil stabilization study aims at improving the compressibility of marine clay by adding of coal ash and cement as the stabilizer. The aim of this study is to verify the physical properties of soft marine clay soil. Then, to determine the effect of compressibility of untreated and treated soft marine clay soil with addition of coal ash and cement (OPC) at different curing periods. The samples are classified as clayey silt with slightly plasticity since the value of plastic index (PI) is less than 7. The result of the maximum dry density is 1580 kg/m^3 while for the optimum moisture content (OMC) is 20%. The void ratio of the sample decreases as the curing periods increases and the optimum ratio of fly ash to bottom ash is 50:50. Compression index and swelling index value signifies the compressibility of a soil and the value of compression index and swelling index decreases as the curing period increases. Thus, through this research the compressibility of marine clay can be improved to support load and decrease the problem of settlement on construction of soft soil.

1. Introduction

Low lands, offshore areas, and coastal corridors as well as other parts of the earth are mostly found to be soft marine clay soil. The most common form of subgrade soil is soft clay, which is inappropriate for use as a roadway subgrade without the aid of soil development procedures due to its great plasticity, weak strength, excessive compressibility, and very low load-bearing capacity [1]. The shear strength of the weak marine clay soil appears to be less than 40 kPa and can be clearly affected by gentle finger pressure. When compared to other types of soils, it is believed that any construction projects built on weak marine clay soil will encounter more challenges. In addition, it is considered to be susceptible to failure due to its high compressibility and problematic properties.

Marine clay has the ability in reducing of inorganic contaminants and considered as low permeability. This sediment is deposited mostly along Peninsular Malaysia's coastal areas. Marine clay is characterized by its microcrystalline nature, and it is composed of clay minerals including illite, kaolinite, and chlorite. Additionally, the soil may contain non-clay minerals such as quartz and feldspar [2,3]. The soils contain a greater proportion of organic matter that acts as a binder. Due to the unpredictability of their performance, marine clay soils in particular may cause significant design challenges for pavements [4]. In addition, due to variations in moisture, they are frequently unstable beneath a pavement and the most susceptible to problems.

Soil stabilization seeks to increase soil strength and resistance to water softening by binding soil particles together, water-proofing soil particles, or a combination of the two. Typically, the technology provides an alternative structural prerequisite solution for any applied problem. Compaction and drainage are the most elementary stabilization techniques. Other additional method is by refining particle size gradation and by adding binders to the weak soils, additional improvement can be achieved. There are several methods to accomplish the soil stabilization. All of these methods are divided into two broad classifications which are chemical stabilization and mechanical stabilization.

Chemical stabilization is the adding of a substance to soil to improve its geotechnical performance, which involves its mechanical and chemical properties. Soil stabilizers can be classified as traditional and non-traditional stabilizers. Traditional stabilizers such as cement, lime,and fly ash, while non-traditional stabilizers consist of a variety combination of chemical agents interacting with the soil. Several research investigations have documented the use of several additives, including cement, lime, fly ash, silica fumes, demolished tile waste, and rice husk ash, for the purpose of chemically stabilizing soft soils [5,6]. Chemical stabilization is a widely used technique in soil remediation due to its cost-effectiveness, environmental sustainability, and high efficiency. The use of indigenous natural and industrial resources, such as coal ash and cement, for soil stabilization has been well recognized for its significant impact on enhancing soil properties. Soil stabilization is a method used to stabilize unbound materials by adding cementitious materials such as bitumen, fly ash, cement, or lime. Stabilized soil materials exhibit superior strength, reduced permeability, and decreased compressibility in comparison to the original soil.

Soft marine clay soil is a kind of soil that exhibits significant compressibility and swellability. It is often encountered when the moisture concentration surpasses its liquid limit. One of the methods that can increase the compressibility of soft soil and reduce the settlement of marine clay is chemical stabilization. Bottom ash and fly ash are examples of chemical stabilization. According to [7], The shear strength of the soft clay was seen to grow significantly at various curing durations as a result of the addition of fly ash, which facilitated pozzolanic reactions. Specifically, the shear strength exhibited an increase ranging from 12 to 39 times the starting strength.

In this research, coal ash is employed as an additional additive and supports ordinary Portland cement, whereas ordinary Portland cement is regarded the primary additive for stabilizing marine clay. As an addition in the stabilization process, coal ash cannot be used on its own. In order to ensure the long-term stabilizing process and provide an element for the pozzolanic reaction, a tiny amount of chemical binder must be added in order to create a strong and durable subgrade layer. Coal ash consists mainly of fly ash and bottom ash, and the production ratio of fly ash to bottom ash is around 80:20 [8]. In this study, the coal ash for the additive was obtained from Tanjung Bin power plant. Four coal-fired power plants can be found in Peninsular Malaysia: Jimah in Negeri Sembilan, Kapar in Selangor, Manjung in Perak, and Tanjung Bin power plant in Johor. Eighty to ninety percent of the ash or unburned material embedded in the flue gas is recovered as fly ash, which is produced by burning pulverized coal in a dry bottom boiler. Dry bottom ash, which makes up the remaining 10–20% of the ash, is a granular, porous, dark grey substance that is mostly the size of sand that is collected in hoppers filled with water at the bottom of the furnace.

2. Methodology

Marine clay was selected as the specified kind of soft clay for this research. Marine clay has been taken from an Iskandar Puteri, Johor, development site. Coal ash, a byproduct of fly ash and bottom ash, is obtained from the Tanjung Bin Power Plant in Johor. Table 1 summarizes the chemical properties of coal ash materials from Tanjung Bin Power Plant. Material characterization is later done for marine clay to identify its physical properties. The physical properties of soft marine clay soil have been studied in accordance with British Standard (BS) 1377:1990.

Table 1. Chemical properties of coal ash materials.

	Tanjung Bin Power Plant		
Chemical properties	[9] Bottom Ash	[10] Bottom Ash	[9] Fly Ash
SiO_2	42.70%	33.70%	51.80%
Al_2O_3	23.00%	12.90%	26.50%
Fe_2O_3	17.00%	6.98%	8.50%
CaO	9.80%	6.34%	4.81%
K_2O	0.96%	1.19%	3.27%
TiO_2	1.64%	0.89%	1.38%
MgO	1.54%	0.65%	1.10%
P_2O_5	1.04%	0.90%	0.90%
Na_2O	0.29%	0.59%	0.67%
SO_3	1.22%	0.30%	0.60%
BaO	0.19%	0.22%	0.12%

Sample preparation is required to determine the engineering properties (void ratio, compression, and swelling) of marine clay when treated with cement and coal ash. In addition, the optimal soil sample mix has also been determined. For the consolidation test, combinations of Ordinary Portland Cement (OPC) and coal ash content have been prepared into a percentage of 2% cement plus 3% coal ash, as shown in Table 2, the tabulation of the ratio of the soil sample. Each coal ash percentage has been carried out in a different ratio of fly ash (FA) and bottom ash (BA). The specimens were stored inside polyethylene bags and placed within a glass desiccator for the purpose of curing period (7 days, 14 days, and 28 days). The specimens were extracted from the polyethylene pouches subsequent to the completion of the curing period, and subsequently, the consolidation test were carried out in adherence to the guidelines set out by BS 1377: Part 5:1990. The consolidation test is used when subjected to vertical loads to determine the consolidation characteristics of low-permeability soils. In this test, in increments of applied stress, the soil specimen is loaded axially. Each increase in stress is kept constant until the primary consolidation has stopped. Throughout this procedure, water dissipates from the specimen, leading to a reduction in height that is assessed at appropriate times. The outcomes of these measurements are utilized to determine the correlation between effective stress and compression or void ratio, in addition to deriving parameters that specify the quantity and rate of compression. The results obtained from the test were then analyzed and discussed.

Table 2. Tabulation ratio between FA and BA mixed with cement and marine clay.

Sample	Percentage by Dry Weight of Soil		
	Cement (%)	FA (%)	BA (%)
UT	0	0	0
FA:BA (30:70)	2	0.9	2.1
FA:BA (50:50)	2	1.5	1.5
FA:BA (70:30)	2	2.1	0.9

3. Result and Analysis

Both untreated and treated marine clay soils were tested using an oedometer. For comparison purposes with the treated specimen, an untreated marine clay specimen was prepared and classified as a control specimen. Table 3 illustrates the results of physical characteristics consisting of maximum dry density, moisture content, and Atterberg's limit. To obtain the properties values of marine clay, physical properties tests were conducted. Since the value of PI is 4.55%, it is classified as clayey silt with slight plasticity.

Table 3. Physical properties test of marine clay soil.

Maximum Dry Density (MDD)	1580 kg/m^3
Optimum Moisture Content (OMC)	20%
Liquid Limit (LL)	27%
Plastic Limit (PL)	22%
Plasticity Index (PI)	5%

The oedometer test was performed on marine clay, both treated and untreated soil. A specimen of treated marine clay was made and put to the test for comparison with the untreated specimens as a control specimen. Each sample of treated marine clay was prepared at different curing periods with a different ratio of coal ash. Within this research investigation, the ratio of coal ash added was 3% with a ratio of 50:50 (FA:BA), 30:70 (FA:BA), and 70:30 (FA:BA) and the experiment was conducted after 7, 14, and 28 days of curing periods. The compression under each load is observed at a suitable interval, typically up to 24 hours for this test. The loading applied was 25 kPa, 50 kPa, 100 kPa, 200 kPa, 400 kPa, and 800 kPa, and the unloading applied was 400 kPa and 200 kPa. Each sample in this investigation had an initial water content that matched the optimal moisture value determined by the compaction test.

Figure 1 compares the compression curve of the untreated marine clay soil and treated marine clay soil with combination of coal ash and cement at different curing periods while Figure 2 compares the compression curve of the treated soil with combination of coal ash and cement at 7 days of curing periods. The graph in Figure 1 shows how the combination of coal ash and cement affect the result of void ratio. It can be seen clearly from the graph that the untreated have dropped sharply during the loading pressure applied. But, for the treated marine clay soil, curing period of 7 days fell rapidly compares to 14 days and 28 days. It proves that the compression curves decrease with the increasing of curing period but not as much as the untreated marine clay soil. The results suggest that the addition of cement and coal ash can improve the compressibility of marine clay soil, as supported by previous research by Pan *et al*. [11].

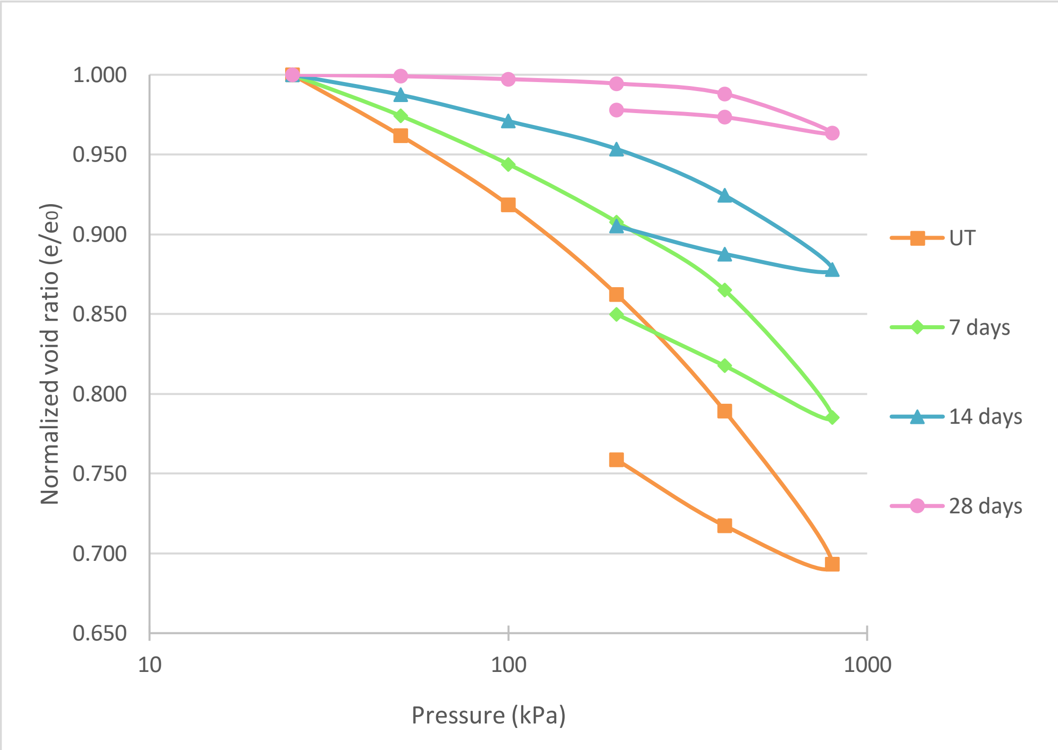

Figure 1. Compression curve of the untreated soil and treated soil with combination of coal ash and cement at different curing periods.

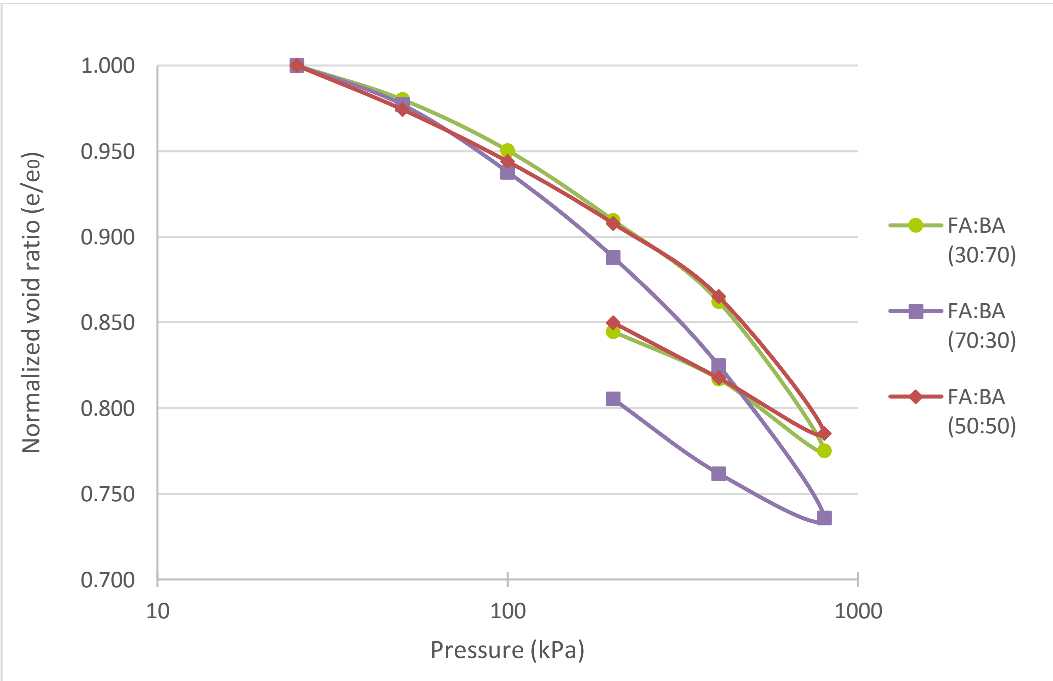

Figure 2. Compression curve of the treated soil with combination of coal ash and cement at 7 days of curing periods.

From Figure 2, it shows that the different ratio between fly ash and bottom ash affect the result of the void ratio. The ratio of 70:30 shows that it has decreased sharply during the loading applied, from about 1.0 to 0.736. This compared with about 0.775 for the ratio 30:70 and 0.785 for the ratio 50:50. The result shows that a ratio of 50:50 was the optimal ratio of both fly ash and bottom ash when mixed with cement as the main stabilizer for treated marine clay soil. From Figure 3, it indicates that the results of the compression index are decreasing as the curing period increases. Further analysis showed that, from zero to 14 days of curing period, the compression index fell rapidly, from 0.229 to 0.116. Meanwhile, from 14 to 28 days, it showed that the compression index dropped slightly from 0.116 to 0.09. It is apparent from the graph that the data from the swelling index is lower than the compression index. As can be seen from Figure 3, the swelling index dropped sharply from zero to 14 days with the data of 0.113 to 0.047, while from 14 to 28 days it shows that the swelling index declined minimally from 0.047 to 0.027. Preconsolidation pressure is the maximum effective vertical overburden stress sustained by a particular soil sample. The pc can be measured using Casagrande's graphical method. Based on Figure 3, from zero to 14 days, the preconsolidation pressure increased sharply with the data, from 160 kPa to 360 kPa. Meanwhile, from 14 to 28 days, it shows a gradual increase of about 360 kPa to 400 kPa. This attenuation in C_c and C_s can be associated with the pozzolanic reaction to produce cementation products (CSH and CAH) that support the external load [12]. Meanwhile, with the increment of curing periods, p_c of treated marine clay soil will also increase. This finding suggests that the pozzolanic reaction enhances the stability of the soft clay matrix, resulting in a significant decrease in the long-term settlement of the soil [13].

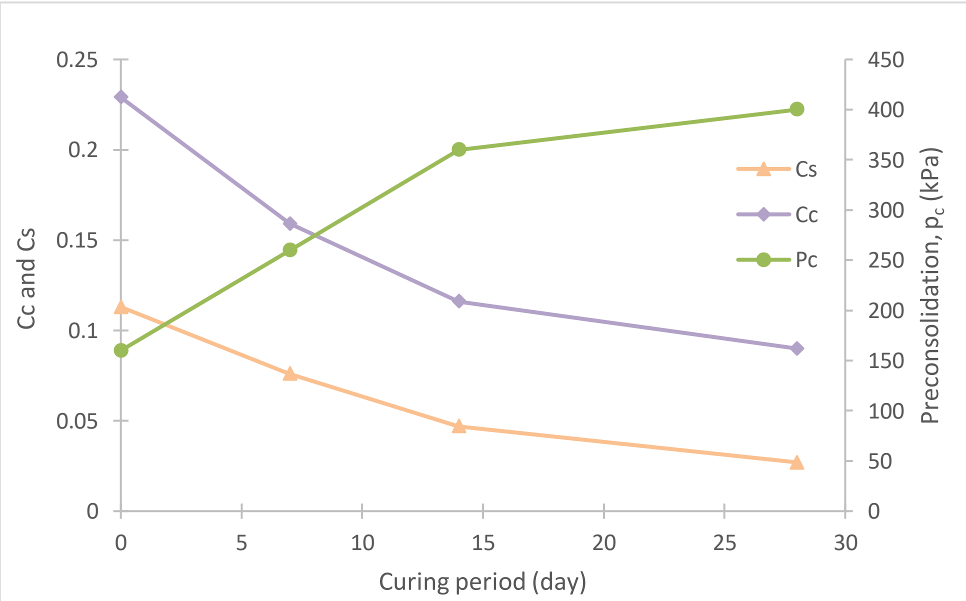

Figure 3. Coefficient of compression, swelling and preconsolidation pressure of the untreated soil and soils treated with combination of coal ash and cement.

4. Conclusions

This research was carried out in an attempt to further elucidate the effects of coal ash as an addition to cement as the main stabilizer on the strength properties of treated marine clay soil. The oedometer test concludes that the void ratio of the treated marine clay soil with cement coal ash reduces as the curing period increases. It is also proven that the strength of the treated soil increases as the curing period increases. At 28 days, the settlement of the soil is smaller than 7 days of curing periods. In term of ratio for fly ash and bottom ash for the coal ash, the optimum ratio of fly ash to bottom ash is 50:50. Coefficient of compression and coefficient of swelling values indicate the compressibility of a soil, and the value of compression and swelling decreases as the curing period increases. Overall, this study verifies that when coal ash and cement are added to marine clay soil, The reactions occur between coal ash and clay particles have the potential to alter soil properties, resulting in enhanced compression strength and shear strength. Consequently, these changes contribute to the increased stability of marine clay.

5. References

[1] Sorsa, A, Senadheera, S, & Birru, Y 2020 Engineering Characterization of Subgrade Soils of Jimma Town Ethiopia for Roadway Design,*Geosciences.***10(94)**.1-17

[2] Mohd Yunus, N Z, Marto, A, Pakir, F, Kasran, K, & Azri Jamal, M A 2015 Performance of Lime-Treated Marine Clay on Strengh and Compressibility Characteristics, *International J of Geomate*.**8(2)** 1232–1238.

[3] Pakir, F , Abdul Karim, A B, Ling, F N L, & Kassim, K A 2013 Effect of humic acid on geochemistry properties of kaolin, Adv Mat Res. **701** 310-313

[4] Jin, L., Yunus, N., Hezmi, M., Rashid, A., Marto, A., Kalatehjari, R., Pakir, F., Mashros, N., & Ganiyu, A 2018 Predicting the Effective Depth of Soil Stabilization for Marine Clay Treated by Biomass Silica KSCE,*Journal of Civil Engineering* **22** 4316-4326.

[5] Krithiga, N., Pujitha, D., Palayam, T., & Revathy, A 2017 *Soil Stabilization Using Lime and Fly Ash*. (April) 510–518.

[6] Jamaludin N, Mohd Yunus N Z, Jusoh S N, Pakir F, Ayub A, Zainuddin N E, Hezmi M A, Mashros, Nordiana 2019 Potential and future: Utilization of waste material on strength characteristics of marine clay I*OP Conference Series: Materials Science and Engineering* Volume 527(1) 1-8

[7] Hassan M A, Makhtar A M, Othman B A, & Marto A, 2013 Shear Strength Improvement of Soft Clay Mixed with Tanjung,*APCBEE Procedia*. **5** 116–122.

[8] Jorat E, Namazi E, & Marto A, 2011 Engineering Characteristics of Kaolin Mixed with Various Percentages of Engineering Characteristics of Kaolin Mixed with Various Percentages of Bottom Ash, *Electron. J. Geotech. Eng*.**16** 841-850

[9] Muhardi, Marto A, Kassim K A, & Makhtar A M 2010 Engineering Characteristics of Tanjung Bin Coal Ash, *Electron. J. Geotech. Eng*.**15** 1117–1129.

[10] Ramzi N I R, Shahidan ., Maarof M Z, & Ali N 2016 Physical and Chemical Properties of Coal Bottom Physical and Chemical Properties of Coal Bottom Ash (CBA) from Tanjung Bin Power Plant *IOP Conference Series: Materials Science and Engineering* (San Fransisco)

[11] Pan L., Liu H., Qiu W., & Yin J. 2023 Effects of Salinity and Curing Time on Compression Behavior of Fly Ash Stabilized Marine Clay KSCE,*Journal of Civil Engineering.* **27** 4141–4151.

[12] Ramelan, A., Nugroho, A., Indriati, T., & Rachmantyo, R. 2021 Structural and Microscopy Characterization of an Alternative Low-Energy Binder Containing Ca(OH)2 as an Alkaline Activator, *Eastern-European J.Enterp. Technol.***3(6(111)** 71-79

[13] Vichan, S., & Rachan, R. 2013 Chemical stabilization of soft Bangkok clay using the blend of calcium carbide residue and biomass ash, *Soils and Foundations*. **53** 272-281.

Acknowledgments

This research was supported by Universiti tun Hussein Onn Malaysia (UTHM) through Tier 1 (vot Q348).