SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Applied Mechanics

Journal homepage:
https://semarakilmu.com.my/journals/index.php/appl_mech/index
ISSN: 2289-7895

Treatment of Marine Clay Strength Behavior by Demolished Tile Materials and Cement

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ARTICLE INFO

Article history:
Received 12 July 2024
Received in revised form 15 August 2024
Accepted 22 August 2024
Available online 30 August 2024

Keywords:
Marine clay soil; unconfined compressive strength; demolished tile waste

ABSTRACT

Known as a problematic soil in the civil engineering field, a sustainable solution to marine clay soil strength behaviour is needed. Another major concern in the engineering field is solid waste management. Demolished Tile Material (DTM) is one of the largest contributors to construction waste. By utilising DTM as a stabiliser product to treat marine clay soil, both problems can be minimized. The primary objective of this study is to assess the improvement in marine clay soil's strength characteristics through the addition of DTM and cement. Various proportions of DTM (4%, 8%, 12%, 16%, and 20%) were incorporated into the soil, with a constant 10% cement content. Unconfined Compressive Strength (UCS) measurements were taken at different curing times (0, 7, 14, 28, and 60 days). Results indicate a significant increase in UCS after treating marine clay with DTM and cement, with the most substantial improvement observed at 16% DTM content. The study also emphasises the role of curing time in enhancing soil strength. The research findings shows that the potential of repurposing DTM for soil stabilisation, reducing construction waste, and promoting environmentally responsible construction practices. This study also contributes to the sustainable development of marine clay areas in Malaysia and offers valuable insights for soil engineering and waste management in construction projects.

1. Introduction

Marine clay is some of the most common soft soil found throughout Malaysia, mainly in the coastal area. However, due to the properties of the soil having weak compressive strength, high moisture content, low permeability, excessive settlement and swelling, it is very unsuitable to be used as a foundation [1]. Due to the increasing demand for land used for development, it is

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https://doi.org/10.37934/aram.124.1.182189

unavoidable to explore the coastal area or even seashore for development expansion [2]. Another major problem faced in the engineering field is construction waste management. Construction waste alone contributed to more than 30% of solid waste worldwide [3]. In Malaysia, laws and legislation regarding construction waste have been implemented. Managing construction waste efficiently is an important issue to be considered in minimizing environmental issues. However, the lack of awareness and attitude of contractors in wanting to conserve the environment has been one of the most difficult factors to solve. Reuse, reduce, and recycle concept needs to be incorporated into every construction project [4]. Demolished tile material contributes to more than 15% of solid waste in a construction project [1]. The materials which consist of granite that has tough properties can be utilized properly in other areas to prevent construction wastage [5]. Portland cement also has been one of the most common bonding agents used in construction. Hardening will occur when in contact with water which causes the hydration reaction that is very useful especially in the engineering field [6].

By having the mindset of turning waste into wealth, using demolished tile materials for beneficial purposes can help reduce solid waste disposal [7]. The most common solution regarding marine clay soil often involves excavating and removing the soil from the site. Aside from that, the use of chemicals is also introduced in treating marine clay soil on-site [8]. By recycling and reusing the waste that is beneficial for soil treatment, waste disposal costs as well as engineering problems can be reduced [9]. Therefore, the main objective of this study is to assess the enhancement in the strength characteristics of marine clay soil after the addition of Demolished Tile Materials (DTM) and cement. Various amounts of DTM were applied to the marine clay soil, but a consistent amount of cement was maintained over the treatment process. The percentages DTM used are 4%, 8%, 12%, 16% and 20% while the cement was fixed at 10%. The Unconfined Compressive Strength (UCS) of the treated and untreated samples is then measured. The sample is subjected to various curing times of 0, 7, 14, 28, and 60 days.

2. Methodology

In this study, marine clay soil was selected, while two stabilisers namely cement and DTM were used. The soil samples were mixed with varying percentages of DTM (4%, 8%, 12%, 16%, and 20%) and subjected to different curing durations (0, 7, 14, 28, and 60 days). In contrast, the cement content remained constant at 10% for all samples.

2.1 Materials

The main material used in this study is marine clay which is identified as a problematic soil. Marine clay was collected from the construction site in the University Tun Hussein Onn Malaysia area. The physical properties of the marine clay were obtained to classify its properties. Table 1 summarizes the fundamental properties of the marine clay utilised in this study.

Marine clay generally consists of clay and silts which are very fine materials. The amount and type of clay minerals present in the soil can influence the physical properties and strength of the soil [10]. Aside from that, the liquid limit and plastic limit of the soil are also important to known. Liquid limit is the moisture content needed for soil to behave like a viscous liquid. The plastic limit is the moisture content needed for soil to deform plastically without failing [11]. Table 2 shows the physical properties of marine clay soil in various locations.

Table 1
Properties of marine clay used

Properties	Results
Plastic Limit (%)	26
Liquid Limit (%)	78
Plasticity Index (%)	52
Particle size distribution (%):	
Gravel	0
Sand	10
Silt	28
Clay	62
Optimum Moisture Content (%)	20
Maximum Dry Density, MDD (kg/m^3)	1617
Specific Gravity, G_S	2.6
pH	5.67

The main mechanical property that has been investigated is the UCS. It is very important to know the UCS of soil before the start of an engineering project. The ability of soil to withstand an axial load needs to be investigated to estimate the ability of the soil in-situ when it is subjected to a load under the structure constructed above.

Table 2
Typical marine clay properties in various location

Location	Iskandar Puteri, Johor	Gelang Patah, Johor	Jeram, Selangor	Shanghai, China
Liquid Limit, LL (%)	58	58	78.8	36.6
Plastic Limit, PL (%)	23	25	34.4	19.66
Plasticity Index, PI (%)	35	33	43.4	16.94
pH	-	2.89	-	8.25
Specific Gravity, SG	-	2.60	2.33	2.7
OMC (%)	21	32	20.5	-
MDD (kg/m^3)	1600	1300	1500	-
UCS (kPa)	23	233.95	210.6	40
Reference	[8]	[12]	[13]	[14]

The cement used was ordinary portland cement obtained from a nearby cement supplier. Table 3 shows the chemical composition of the cements that were used in this study.

Table 3
Chemical composition of cements

Chemical Composition (%)								
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI
18.3	5.00	2.7	60.1	1.15	3.21	0.08	0.00	7.22

DTM is bought from a factory in Johor Bahru, Malaysia. This is to control the minerals inside the DTM additive. The DTM was then taken from the tile waste in the field area and crushed using a crusher machine. Next, the crushed DTM was pulverised using the Los Angeles Abrasion Machine (LAA) to form fine. Lastly, the DTM was sieved into 63 µm. The size of 63 µm was specifically chosen based on the hypothesis that the finer the particles, the higher the strength for stabilising clay soil.

This may be attributed to the size of the DTM, which can contribute to the minimising of the clay pores. Plus, different percentages of DTM in the range of 4% to 20% of fine sizes were also considered in order to determine the effects of DTM on marine clay soil.

2.2 Preparation of Sample

The specimens were prepared with optimum moisture content (20%) and maximum dry density (1617 kg/m3) of natural soils. The marine clay sample of 500g was prepared and mixed with different additives, namely 4%, 8%, 12%, 16%, and 20%, and cured at a specified time of 7, 14, 28, and 60 days. These specimens are put into a mould with dimensions of 50 mm in diameter and 100 mm in height. Then the moulded specimens were left to cure in the polythene bottle and placed above water in a closed container in a room where the temperature was 27±2°C. After the curing process was done, an unconfined compressive test (UCT) was performed on each specimen. This test was performed on the specimen that has been treated with DTM and cement. The strength before failure was recorded and analysed.

3. Results

Both untreated and treated samples are compacted in the UCT mould. It is tested with an automated unconfined compressive stress machine. The strain rate set for the test is 1%/min, and the data are tabulated. The UCS of untreated and treated samples is tabulated in Table 4. It summarised compressive strength according to its mixture content and curing period respectively.

Table 4
Unconfined Compressive Strength of Treated and Untreated Soil

Sample	Unconfined Compressive Strength (kPa)				
	Curing Period (days)				
	0	7	14	28	60
Untreated (UT)	120	120	120	120	120
Clay + 10%Cement	208	274	302	358	480
Clay + 10%Cement + 4% DTM	431	517	711	840	918
Clay + 10%Cement + 8% DTM	528	550	725	934	1045
Clay + 10%Cement + 12% DTM	582	709	861	1117	1469
Clay + 10%Cement + 16% DTM	1046	1136	1594	1740	2401
Clay +10%Cement + 20% DTM	658	878	1095	1437	1646

Table 4 clearly shows that the treated sample has a significant increase in UCS value. Further comparisons can be made in terms of additive content and curing period.

3.1 Additives Content

Figure 1 depicts the effect of 10% cement and various percentages of DTM on the unconfined compressive strength of treated marine clay. It is demonstrated that increasing the DTM content increases the UCS of treated marine clay soil from 4% to 16% of additive amounts at all curing periods. However, the UCS value slightly decreased at 20% of DTM content for the specimens at all curing periods. For example, for 7 days of the curing period, the UCS of untreated soil increased from 120 kPa to 1136 kPa after the addition of 16% DTM and decreased to 878 kPa when 20% DTM was added. It can be concluded that the addition of DTM of more than 16% reduced the compressive strength of soil samples. Then, progressive increments in strength were seen when 16% of DTM was added to the marine clay soil at all curing periods. For instance, at 60 days curing period, C10% + 16% DTM treated sample achieved a compressive strength of 2401 kPa, which is approximately 20 times greater than the untreated soil strength (120 kPa) whereas for C10% + 20% DTM treated samples, the numbers are approximately 14 times greater than the untreated soil strength. Furthermore, the addition of C10% + 16% DTM showed the biggest increment compared with the other increment DTM. Besides that, the increase in UCS from the addition of C10% + 4% to 12% DTM is smaller compared to the increase in UCS with the addition of C10% + 12% to 16% of DTM. The slight decrease of treated soil strength at C10% + 20% of DTM content might be due to the limited presence of free calcium ions to promote a pozzolanic reaction [15]. This is because 20% DTM as a filler has a significant difference with 10% cement as the binding agent. The filler will only fill the void on untreated marine clay and will not provide an adequate binding agent to increase the strength performance [12].

In contrast, the total strength of the treated soil is enhanced with increasing DTM, which may be related to the availability of SiO_3 ions inside the treated soil samples to allow the pozzolanic processes [16]. Furthermore, the substantial increase in unconfined compressive strength (UCS) of specimens treated with DTM may be attributed to the ion exchange process and the growth of cementitious compounds, resulting in a reduction in the porosity of the treated soil. The expansion of the UCS saw a significant increase due to an increase in the DTM as a result of the presence of magnesium and aluminium. These elements acted as catalysts in the production of a few cementation compounds. The decrease of the UCS after being treated with 20% DTM could be brought about by the alkalinity of DTM (pH = 8.11), which achieved the necessary condition for chemical reactions involving soil particles [17,18].

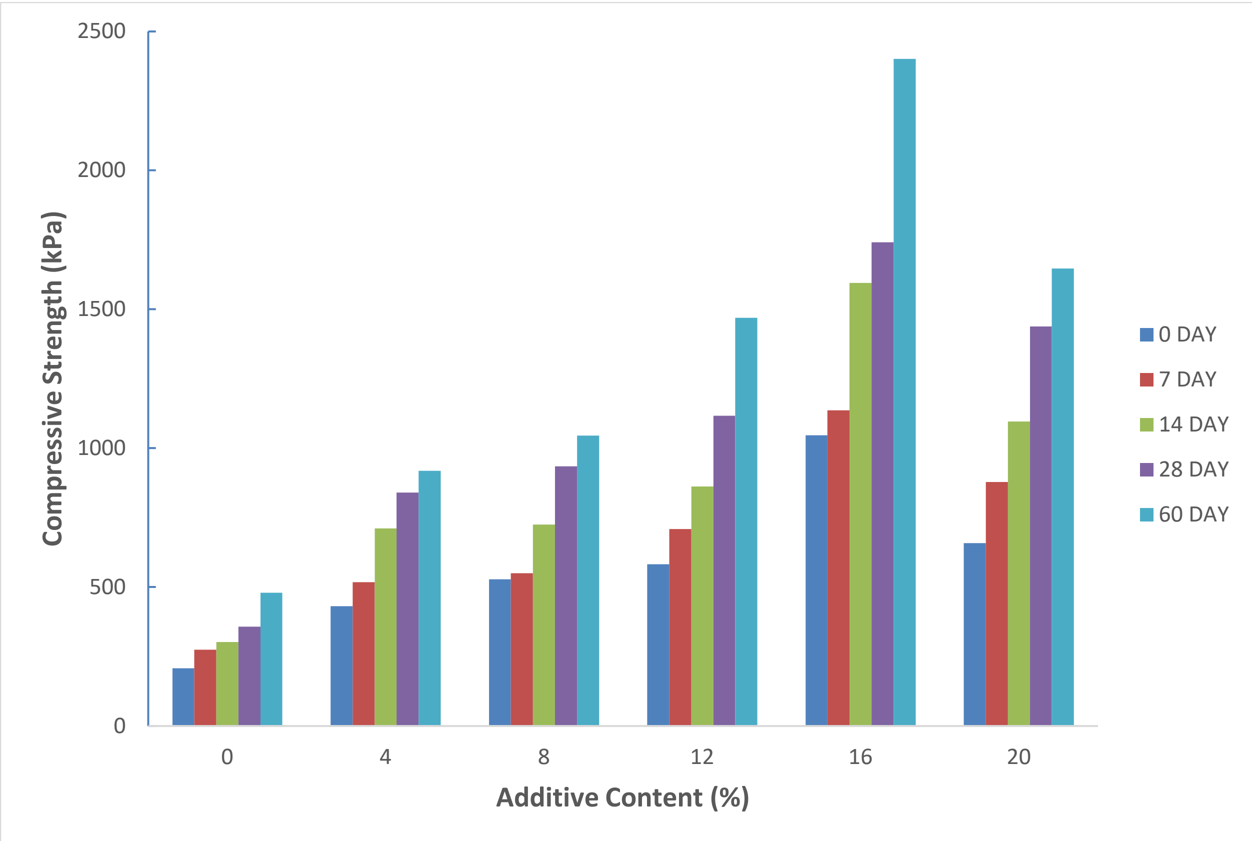

Fig. 1. Effect of C10% and DTM with different percentages on unconfined compressive strength of treated marine clay

3.2 Curing Period

Figure 2 shows the strength of the untreated marine clay soil and marine clay soil treated with 10% cement and different percentages of the DTM stabiliser at different curing periods. As shown in the Figure 2, the UCS values of the treated marine clay soils increased with the increase of the curing periods, but these increments were relatively small for C10% + DTM 0% to 8% for 0 to 60 days of curing periods. For instance, for soil treated with C10% + DTM 12%, the UCS value of 1117.03 kPa was achieved after 28 days of curing period (9 times greater than untreated soils) while the UCS value after 60 days curing period was 1469 kPa (12 times greater than untreated soil). This suggests that the early stage of curing time was caused by an ion exchange reaction for the textural modifications [19,20]. Meanwhile, as the curing time frame increased, the strength increased because of the formation of cementitious products (hydrants) from DTM stirred with cement that was formed through pozzolanic reactions. The increment of UCS can be attributed to the hydration process that occurs due to the presence of cement in the specimen. The process continues to develop over time and bond the aggregates in the specimen; thus, increasing compressive strength [21,22].

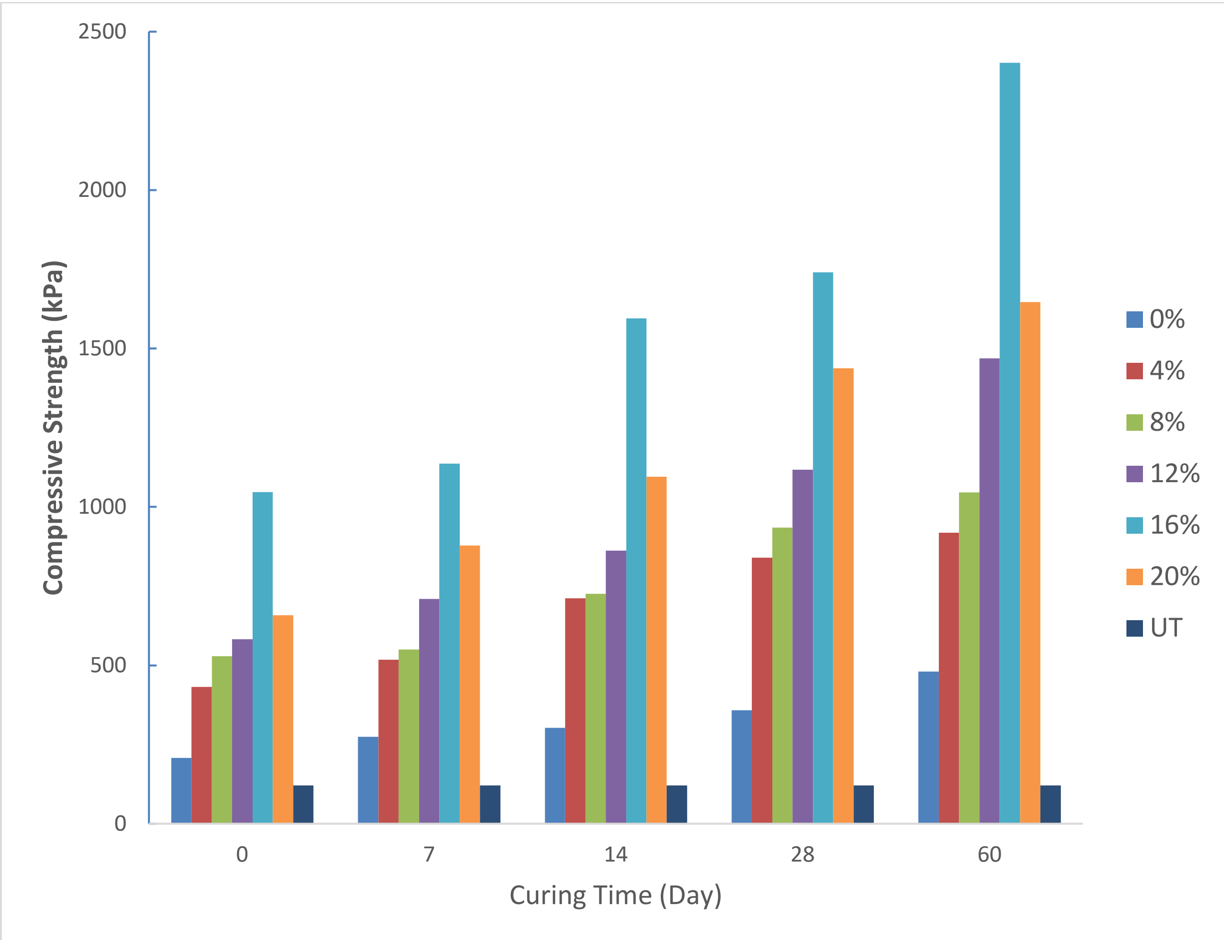

Fig. 2. Effect of the curing period on the unconfined compressive strength of marine clay treated with C10% and various concentrations of DTM

4. Conclusions

Based on this study, it is evident that the inclusion of Demolished tile waste (DTM) in cement has a discernible impact on the characteristics and strength of the soil. The findings reveal that the addition of DTM and cement significantly improved the Unconfined Compressive Strength (UCS) of the soil, with the most substantial gains observed at 16% DTM content. The impact of curing time on soil strength was also evident, with prolonged curing periods leading to further improvements. These results underscore the feasibility of using DTM as a sustainable and cost-effective soil stabilisation agent, providing a practical solution to mitigate the engineering challenges posed by marine clay soil. Furthermore, the utilization of DTM contributes to reducing construction waste, aligning with environmentally responsible construction practices and the principles of the circular economy. In conclusion, this study emphasises the importance of innovative and eco-friendly approaches to addressing soil engineering issues and construction waste management. The repurposing of DTM offers a promising avenue for sustainable development in coastal regions, facilitating the expansion of construction activities while minimizing environmental impact. Further research and practical applications of this approach are encouraged to advance the field of soil engineering and promote sustainable construction practices on a broader scale.

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

References

[1] Jamaludin, N., NZ Mohd Yunus, S. N. Jusoh, F. Pakir, A. Ayub, N. E. Zainuddin, M. A. Hezmi, and Nordiana Mashros. "Potential and future: Utilization of waste material on strength characteristics of marine clay." In *IOP Conference Series: Materials Science and Engineering*, vol. 527, no. 1, p. 012003. IOP Publishing, 2019. https://doi.org/10.1088/1757-899X/527/1/012003

[2] Bohari, Asmah Alia Mohamad, Martin Skitmore, Bo Xia, Melissa Teo, Xiaoling Zhang, and Khairul Naim Adham. "The path towards greening the Malaysian construction industry." *Renewable and Sustainable Energy Reviews* 52 (2015): 1742-1748. https://doi.org/10.1016/j.rser.2015.07.148

[3] Islam, Rashidul, Tasnia Hassan Nazifa, Adhi Yuniarto, ASM Shanawaz Uddin, Salmiati Salmiati, and Shamsuddin Shahid. "An empirical study of construction and demolition waste generation and implication of recycling." *Waste management* 95 (2019): 10-21. https://doi.org/10.1016/j.wasman.2019.05.049

[4] Begum, Rawshan Ara, Chamhuri Siwar, Joy Jacqueline Pereira, and Abdul Hamid Jaafar. "Attitude and behavioral factors in waste management in the construction industry of Malaysia." *Resources, conservation and recycling* 53, no. 6 (2009): 321-328. https://doi.org/10.1016/j.resconrec.2009.01.005

[5] Hojamberdiev, Mirabbos, Ashraf Eminov, and Yunhua Xu. "Utilization of muscovite granite waste in the manufacture of ceramic tiles." *Ceramics International* 37, no. 3 (2011): 871-876. https://doi.org/10.1016/j.ceramint.2010.10.032

[6] Kang, Gyeongo, Takashi Tsuchida, and A. M. R. G. Athapaththu. "Engineering behavior of cement-treated marine dredged clay during early and later stages of curing." *Engineering Geology* 209 (2016): 163-174. https://doi.org/10.1016/j.enggeo.2016.05.008

[7] Esa, Mohd Reza, Anthony Halog, and Lucia Rigamonti. "Strategies for minimizing construction and demolition wastes in Malaysia." *Resources, Conservation and Recycling* 120 (2017): 219-229. https://doi.org/10.1016/j.resconrec.2016.12.014

[8] Pakir, Faizal, Aminaton Marto, Nor Zurairahetty Mohd Yunus, Saiful Azhar Ahmad Tajudin, and Choy Soon Tan. "Effect of sodium silicate as liquid based stabilizer on shear strength of marine clay." *Jurnal Teknologi* 76, no. 2 (2015). https://doi.org/10.11113/jt.v76.5432

[9] Marzouk, Mohamed, and Shimaa Azab. "Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics." *Resources, conservation and recycling* 82 (2014): 41-49. https://doi.org/10.1016/j.resconrec.2013.10.015

[10] Braja M. Das and K. Sobhan, “N,” in Principle of Geotechnical Engineering, 9th ed., Boston: Cengage Learning, 2017.

[11] Shimobe, Satoru, and Giovanni Spagnoli. "Fall cone tests considering water content, cone penetration index, and plasticity angle of fine-grained soils." *Journal of Rock Mechanics and Geotechnical Engineering* 12, no. 6 (2020): 1347-1355. https://doi.org/10.1016/j.jrmge.2020.02.005

[12] Zainuddin, Nurul, Nor Zurairahetty Mohd Yunus, Mohammed Ali Mohammed Al-Bared, Aminaton Marto, Indra Sati Hamonangan Harahap, and Ahmad Safuan A. Rashid. "Measuring the engineering properties of marine clay treated

with disposed granite waste." *Measurement* 131 (2019): 50-60. https://doi.org/10.1016/j.measurement.2018.08.053
[13] Emmanuel, Endene, Lee Li Yong, Vivi Anggraini, and Pooria Pasbakhsh. "Can halloysite nanotubes be used to remediate zinc and lead-contaminated marine clay? A solidification/stabilization approach." *Applied Clay Science* 186 (2020): 105441. https://doi.org/10.1016/j.clay.2020.105441
[14] Khalid, Usama, C. C. Liao, Guan-lin Ye, and Santosh Kumar Yadav. "Sustainable improvement of soft marine clay using low cement content: a multi-scale experimental investigation." *Construction and Building Materials* 191 (2018): 469-480. https://doi.org/10.1016/j.conbuildmat.2018.10.034
[15] Yu, Hao, Xin Huang, Jianguo Ning, Baolin Zhu, and Yin Cheng. "Effect of cation exchange capacity of soil on stabilized soil strength." *Soils and Foundations* 54, no. 6 (2014): 1236-1240. https://doi.org/10.1016/j.sandf.2014.11.016
[16] Yu, Lehua, Shuangxi Zhou, and Wenwu Deng. "Pozzolanic activity of volcanic rocks from Southern Jiangxi Province, China." *Journal of Sustainable Cement-Based Materials* 5, no. 3 (2016): 176-198. https://doi.org/10.1080/21650373.2015.1010660
[17] Al-Bared, Mohammed Ali Mohammed, Aminaton Marto, Nima Latifi, and Suksun Horpibulsuk. "Sustainable improvement of marine clay using recycled blended tiles." *Geotechnical and Geological Engineering* 36 (2018): 3135-3147. https://doi.org/10.1007/s10706-018-0525-8
[18] Jahidin, Ridzuan, Aminaton Marto, Faizal Pakir, and Siti Norafida Jusoh. "Unconfined compressive strength of compacted marine clay treated with magnesium chloride." In *AIP Conference Proceedings*, vol. 2355, no. 1. AIP Publishing, 2021. https://doi.org/10.1063/5.0053471
[19] Latifi, Nima, Amin Eisazadeh, Aminaton Marto, and Christopher L. Meehan. "Tropical residual soil stabilization: A powder form material for increasing soil strength." *Construction and Building Materials* 147 (2017): 827-836. https://doi.org/10.1016/j.conbuildmat.2017.04.115
[20] Nor, Ahmad Hakimi Mat, Saiful Azhar Ahmad Tajudin, Faizal Pakir, Mohd Erwan Sanik, and Salman Salim. "Influence of Biomass Silica Stabilizer on Unconfined Compression Strength of Sodium Silicate Stabilized Soft Clay Soils." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 28, no. 1 (2022): 97-105. https://doi.org/10.37934/araset.28.1.97105
[21] Pu, Shaoyun, Zhiduo Zhu, Weilong Song, Yu Wan, Hairong Wang, Shigong Song, and Jun Zhang. "Mechanical and microscopic properties of cement stabilized silt." *KSCE Journal of Civil Engineering* 24 (2020): 2333-2344. https://doi.org/10.1007/s12205-020-1671-0
[22] Ay, Nuran, and Mevlüt Ünal. "The use of waste ceramic tile in cement production." *Cement and Concrete Research* 30, no. 3 (2000): 497-499. https://doi.org/10.1016/S0008-8846(00)00202-7