Malaysian Journal Of Civil Engineering

Full Paper

SHORT COMMUNICATION: EFFECT OF CURING TIME ON APPLICATION OF JAPANESE TRADITIONAL FORMULATION ON PEAT IN MALAYSIA

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Article history
Received
04 July 2025
Received in revised form
26 October 2025
Accepted
28 October 2025
Published online
01 December 2025

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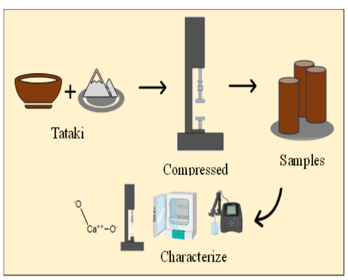
Graphical abstract



Abstract

Working with peatland is very challenging due to its characteristics of low shear strength, high compressibility, and high-water content. Japanese traditional methods called tataki, an earthen floor with a formulation of soil with lime, bittern, and salt, and compact with beating, were well known for their ground enhancement for decades before the introduction of cement in construction industry. Therefore, the present study applied this tataki traditional method with some modification to peat soil in Malaysia. The effect of curing time on peat characteristics was observed up to 182 days. Kinetic models of Korsmeyer-Peppas, Higuchi, zero order, and first order for water-holding capacity flow were determined. The results showed that different curing time has not significantly affected soil shrinkage, pH values, or soil density ($p>0.05$). However, it has significantly affected the moisture content, soil strength, and strain at failure of soil ($p<0.05$). The kinetic study showed that the water-holding capacity inside the soil followed the Korsmeyer-Peppas and Higuchi models ($R^2 \leq 1$). Based on the experimental results, it was evident that the Japanese traditional formulation also worked well with peat soil in Malaysia. The chemical reaction of calcium hydroxide with peat soil could help in better understanding factors that might influence the peat performance.

Keywords: Peat, curing time, Japanese traditional formulation, tataki, characteristics

1.0 INTRODUCTION

Peat is a soil that is weaker than other inorganic soils. Peat can be found in many locations throughout the world especially in the conditions that are suitable for their accumulation and formation. As a weaker soil, peat has many difficulties to work on, especially for engineering construction. Peat and other organic soils are known as soft soils that tend to instability, massive principal, and long-term settlement even with moderate loads [1,2]. Peat also can shift their feature chemically and biologically, hence changing their mechanical properties like compressibility, shear strength, and hydraulic conductivity when in the form of humification. Pouring groundwater can cause them to shrink and oxidize, thereby increasing their permeability and compressibility. Due to this, peat has very low shear strength to work on [1, 2].

Traditional Japanese architecture typically uses tataki, particularly as a floor finish at the entryway. It is created by combining soil, water, bittern, and slaked lime, then kneading and pressing the mixture. Making tataki requires very little equipment and supplies. At least 10,000 years ago, during the Jomon period, this Japanese practice was developed. Before cement and concrete gained popularity in the contemporary period, these techniques were employed for ground preparation, mounding a building's foundation, and finishing flooring at entrances. A traditional farmhouse's inhabitants, for example, used a tataki floor as though it were outside to breed cattle, make meals, and carry out interior agricultural tasks [3, 4].

Study by Sugawara [3] on clay soil applied Japanese traditional method resulted in 17.5 N/mm^2 of compressive strength with different ratio of slaked lime and the curing time is 2hrs. Modified formulation on peat soil by Md Yusof et al [5] secured average UCS after 28 days of curing with 25.388 kPa and the study stopped at 28days of curing. Therefore, the purpose of this study is to investigate the effect of curing time on the application of Japanese traditional formulation on peat soil in Malaysia with extended curing time up to 182 days as a continuation study from our previous (data not shown). The specific objectives of this work are to; 1) determine physical, chemical and mechanical peat characteristics with tataki improvement, 2) test on kinetic models as to determine water-holding capacity flow, and 3) propose the chemical mechanism of tataki formulation in peat.

2.0 METHODOLOGY

2.1 Materials

Analytical grade standard of calcium hydroxide was used for this study by referring to tataki formulation with little modification [3]. The chemical was brought from National Institute of Technology, Kagoshima Kosen, Japan (Hayashi Pure Chemical IND., LTD).

2.2 Soil Sampling

In 2024, soil samples were taken from selected location in Pontian, Johor. The surface of soils was removed and the soil were collected approximately at 0.5 m deep before reaching the water level of the soil. Basic characteristics of the collected soil were dark brown, high water content (using Von Post scale technique), and very acidic (pH test in the laboratory). The collected soil also included small branches and roots, and the samples were stored in airtight containers for further analysis. In the laboratory, the samples were then air-dried at room temperature and sieved with a 0.5 µm size prior to characterization. During sample pre-treatment, the initial moisture and pH value were monitored (95.86% and 3.09), respectively. For the curing procedures, all the sample was kept in the sample container and the container was then left-open in the laboratory at room temperature to mimic actual environment of peat soil at the same time to avoid unwanted weather that might disturb overall curing procedures.

2.3 Analytical Methods

Soil samples were analyzed based on standard methods as tabulated in Table 1.

Table 1 Standard methods reference for this study

Analysis	Standards
UTEST Automatic Mechanical Compactor	ASTM and AASHTO
pH values	British Standard BS8601:2013
Moisture content	British Standard BS EN 1097-5 2008
Unconfined Compressive Strength (UCS)	ASTM D2166

Briefly, after adding 2.5% calcium hydroxide (by considering our findings from previous study), the soil was mixed rigorously until the chemical was completely mixed with the soil. Then, the sample was left for one hour before being compressed. After one hour of incubation, the sample was collected for moisture content and pH analysis. The initial moisture and pH value after adding the chemical were 125.11% and 5.73, respectively. The increasing in the moisture content was discussed in section 3.4, respectively.

The analysis began with the samples being cured at different time intervals of 7, 28, 91, and 182 days.

2.4 Kinetic Models For Water Loss During The Study

Since there is no measurement of equilibrium moisture according to British Standard BS EN 1097-5 2008, the study applied non-equilibrium modeling approaches for the estimation of water flow in soil during curing time. The kinetic mathematical models were categorized based on model structure and complexity of biogeochemical reactions considered namely, 1) Korsmeyer-Peppas, 2) Higuchi, 3) zero order, and 4) first order model [6, 7].

Korsmeyer model was plotted for the determination of flow kinetics as log cumulative percentage water holding capacity versus log time. The equation used is as follow;

$$\log Mt/M\infty = k (\log t)n \quad (1.0)$$

Where log Mt/M∞ indicates log cumulative percentage water holding capacity and log t indicates log time. "k" represents the water holding rate constant while "n" refers to the flow exponent. Korsmeyer uses the value of n to characterize the flow mechanism where n = 0.5 is for Fickian water flow, 0.45 < n = 0.89 is for Non-Fickian water flow mechanism, whereby n = 0.89 is for Case II (relacational) water flow mechanism and n more than 0.89 is equal to Super case II flow [6, 7].

The second model is Higuchi. Higuchi derived the equation for Higuchi model in the form of cumulative percentage water holding capacity versus square root of time where the equation is as follows;

$$ft = Q = kH (\sqrt{t}) \quad (2.0)$$

Where kH refers to Higuchi dissolution constant and "√t" is the square root of time.

Zero and first order model expressed the equation for water holding capacity kinetics as $Qt = k_0t$ for the graph of cumulative amount of water holding capacity versus time and $\log C = \log C_0 - kt/2.303$ for the graph for log cumulative percentage of water holding remaining versus time [6, 7].

2.5 Statistical Analysis

Each sample had at least three readings of each experiment, and the results were presented as an average and standard deviation. Duncan's multiple range test (DMRT) with a significance level of R = 0.05 was used to calculate the significant difference for each associated finding using ANOVA IBM SPSS Statistics v27.

3.0 RESULTS AND DISCUSSION

3.1 Effect of Curing Time On Physical Characteristics Of Peat Sample

After the compression process, the physical characteristics of peat sample for each time interval were determined and tabulated in Table 2.

Table 2 Resultant samples from each curing time

Curing time (Days)	Mass (g)	Height (mm)	Diameter (mm)
7	81.79± 0.56	80.94± 0.30	38.02±0.13
28	68.47± 0.12	79.84± 0.19	35.23± 3.47
91	55.67± 0.55	76.72± 0.40	35.72± 0.10
182	52.40± 0.10	74.85± 0.14	34.93± 0.20

From Table 2, as the curing time increasing, the mass, height, and diameter of the samples were decreased. From standard deviation analysis, it is noted that on 28 days of curing time, the samples are highly fluctuated and not homogenous distribution in the diameter size compared to other samples in other curing days. This sample perhaps has greatly loss in their size due to hydration process or perhaps due to an error during sample preparation that impacted on their size after 28 days of curing. Study by My Yusof et al [5] on the effect of curing time on peat soil formulated with modified formulation also showed similar trend on 7 days (for second reading) of curing with 6% of coconut shell coal ash (CSCA) and fly ash (total curing time is only 28days).

3.2 Effect of Curing Time On Shrinkage Percentage Of Peat Sample

The percentage of sample shrinkage is presented in Figure 1. From figure, it is noted that for the first 7 days of curing, there is no shrinkage occurred to the sample. As curing time increased to 28 days, the samples started to greatly shrink as drying time increased. After 91 days, the sample has very slow shrink and the shrinkage increased back after 182 days of curing. The shrinkage sample indicates that the soil-water mixture was completely saturated or non-saturated that can observe in volume change [8]. One-way ANOVA analysis stated that the curing time has no significantly affected the sample in this study ($p>0.05$). Biggest error bar is due to the homogeneity of diameter size that fluctuated on 28 days of curing that may influence the total volume of overall sample (refers Table 2).

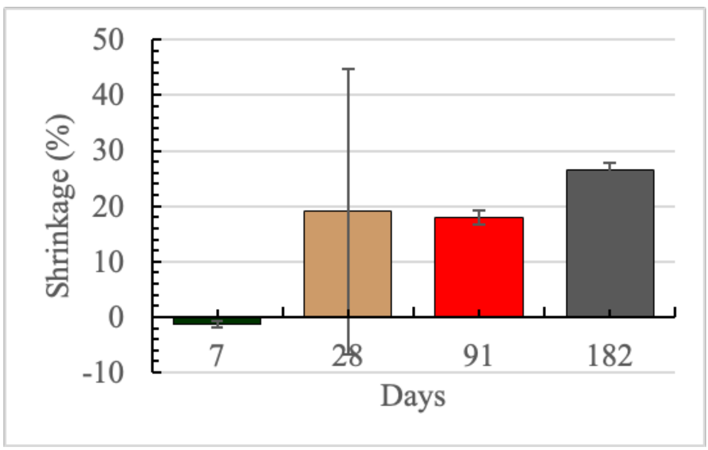


Figure 1 Effect of curing time on shrinkage activity of peat sample

3.3 Effect of Curing Time On Ph Values Of Soil

The effect of curing time on pH values of the sample can be seen in Figure 2. From figure, the pH values of the samples on 7 days of curing decrease (4.43) as compared to initial pH values after applying tataki (5.73), respectively. But the pH value of the samples increases a bit on 28 days of curing (4.55) and reduced back after 91 days of curing (4.45). On 182 days of curing, the pH value is increased but almost like the value on 91 days (4.46). Jiang et al [9] found similar reduction of pH value after testing with 6% lime incorporation. These modifications show that the pozzolanic reaction is a lengthy process that lowers pH and consumes alkalinity. This can be proved by their study which found that with the increase in curing time, the pozzolanic-related calcium rises from zero at 1 day to 0.298 mol/kg at 270 d and further to 0.473 mol/kg after 30 years [9]. However, by referring to this study, statistical analysis shows that the curing time has no significantly affected the pH value of soil after applying this formulation. The reduction in pH values after several days of curing is because of carbonation effect of calcium with carbon from soil as well as environment carbon that may reduce the pH value from early mixing. Carbonation is the process by which lime reacts with atmospheric carbon dioxide to produce calcium carbonate, which is thought to have a cementing effect (refers to figure part II) [10, 11]. At the beginning of applying tataki formulation, the reaction is between acidic soil with calcium hydroxide that increasing the pH value of original soil (from 3.09 to 5.73). This can be explained from the structure in refers to figure part I in Figure 3. The present of oxygen react with hydrogen will increase the pH value of soil, thus increasing alkalinity of soil. However, as curing time increasing, calcium will react with carbon following the reduction of water holding capacity in soil (Figure 1) to form calcium carbonate (part II). Detail chemical reaction is depicted in Figure 3. However, the resultant pH values are in the range of normal pH of peat soil. Mahyan et al [8] stated that in the tropics' region, peat soil is usually acidic, with a pH value ranging from 3 to 4.5, respectively. Study by Md Yusof et al [5] showed similar findings where the pH of soil in their study is 3.42, respectively, but there is no study on pH value after different curing time applied.

3.4 Effect of Curing Time On Moisture Content Of Soil

The effect of curing time on moisture content of soil is presented in Figure 4. It is noted that, the moisture of soil is decreased as curing time increases. This is due to the reduction of water holding capacity from soil. In the beginning, after applying tataki formulation, the moisture is increasing from 95.86% (original) to 125.11% (with calcium hydroxide). After 7 days of curing, the moisture is reduced to 76.13% and 48.08% on 28 days of curing, respectively. But the moisture is tremendously decreased to 23.99% after 91 days of curing and further to 16.93% on 182 days of curing, respectively. This reduction showed the loss of water due to hydration process from time to time. Omoregie et al., [12] stated that this cementation process can influence the hydrological properties of soil, such as in term of permeability, infiltration rates, and water retention capacity, offering dual benefits of enhanced slope stability and improved water management. One-way ANOVA revealed that the curing time is significantly affected the moisture content of soil ($p<0.05$). This can be predicted from kinetic models for the flow of water holding capacity through Korsmeyer-Peppas, Higuchi, zero order, as well as first order model (Table 3). Study by Md Yusof et al [5] showed that the optimum moisture content from their study is 42.31%, respectively.

Table 3 Kinetic models of water holding capacity for non-equilibrium approaches

	Korsmeyer-Peppas		Higuchi	Zero order	First order
	R^2	Slope 'n'	R^2	R^2	R^2
Soil samples	0.9855	-0.2261	0.9855	0.9449	0.9449

From Table 3, it shows that the flow of water holding capacity is fixed to model Korsmeyer-Peppas as well as Higuchi as their R^2 is approaching to 1. From the model of Korsmeyer-Peppas, it shown that the water holding capacity is followed normal Fickian diffusion coefficients ($n \leq 0.5$) of which from high amount of water to lower. This can be confirmed from the reduction of moisture due to hydration process during curing time [13]. On the other hands, Higuchi model showed the water reduction is constant through the pore or reaction with calcium hydroxide in semi-solid/solid samples (Figure 5) [14].

3.5 Effect of Curing Time On Soil Strength

The effect of curing time on soil strength can be found in Figure 6. From figure, the strength of soil increases as the curing time increasing. Within 7 days of curing, the strength of soil is 136.80 kPa. At 0 day, the sample is totally broken due to high moisture content after applying tataki formulation (125.11%). Also, there is no yet cementation or pozzolanic reaction to occur on 0 day of curing. The strength increases from 136.80 kPa at 7 days of curing to 299.56 kPa after 28 days of curing, respectively. At 91 days, the strength is 380.70 kPa and increases again after 182 days of curing (469.31 kPa). This is perhaps due to carbonation and pozzolanic affect that increasing in bonding, thus reducing the porosity (Figure 2 and 3). The carbonation occurred can be predicted from the pH values of soil [9, 15, 16]. One-way ANOVA analysis revealed that the curing time is significantly affected the strength of soil ($p<0.05$). Study by Md Yusof et al [5] showed that the maximum UCS after 0, 7, 14 and 28 of curing days with highest amount of CSCA formulated with fly ash were 25.388 kPa, 29.253 kPa, 36.611 kPa and 39.953 kPa, respectively.

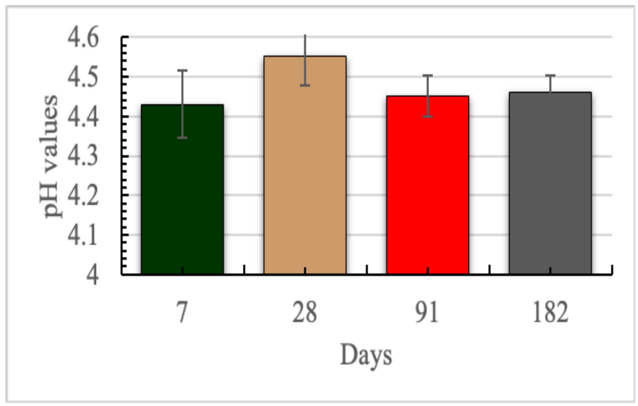


Figure 2 Effect of curing time on pH soil

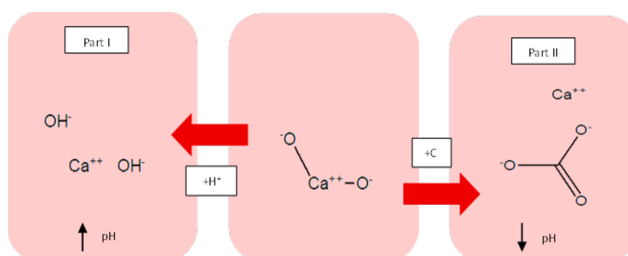


Figure 3 Chemical reaction of calcium hydroxide in soil

3.6 Effect of Curing Time On Strain Of Soil

The effect of curing time on strain at failure is presented in Figure 7. From figure, it is noted that the strain at failure increases as the curing time increasing. In 7 days curing of sample, the strain can be found as 0.19%. The value increases to 0.36% after 28 days of curing. Then, the strain increases again to 0.50% after 91 days of curing. After 182 days of curing, the strain exhibit to value 0.60%. This situation occurred when agglomeration of the soils formed at the bonding sites that will alter the soil structure, and brittle failure was observed for the soils applying tataki formulation. Agglomeration occurred perhaps due to carbonation affect in the soil (**Figure 2, 3,** and **6**) [17]. Statistical analysis showed that the curing time has significantly affected the strain at failure of soil ($p<0.05$).

3.7 Effect of Curing Time On Soil Density

The effect of curing time on soil density can be observed in Figure 8. The density of the soil fluctuates as the curing time increasing. From figure, the density of the soil after curing at 7 days is 0.89 g/cm^3, but increased to 0.90 g/cm^3 after 28 days of curing. The density is reduced to 0.72 g/cm^3 after 91 days of curing and increased a bit to 0.73 g/cm^3 after 182 days of curing. This trend is similar to pH values of soil where on 28 days, the pH increases but after 91 days and above, the pH showed decreasing. This is perhaps due to carbonation effect that influence the density of soil as the mass and the volume of the sample with moisture decreases from time to time (Table 2 and Figure 4). However, One-way ANOVA test revealed that the curing time is not significantly affected the density of soil throughout this study ($p>0.05$). Study by Md Yusof et al [5] found that maximum dry density of their peat soil is 0.623 Mg/m^3, respectively.

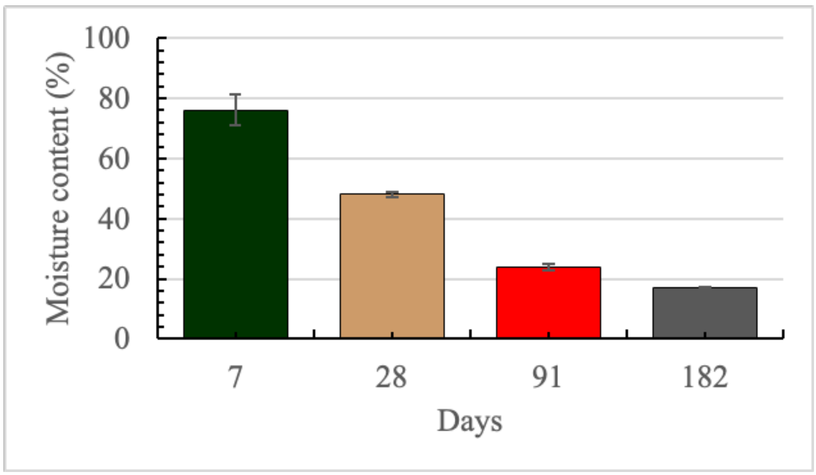


Figure 4 Effect of curing time on moisture content of soil

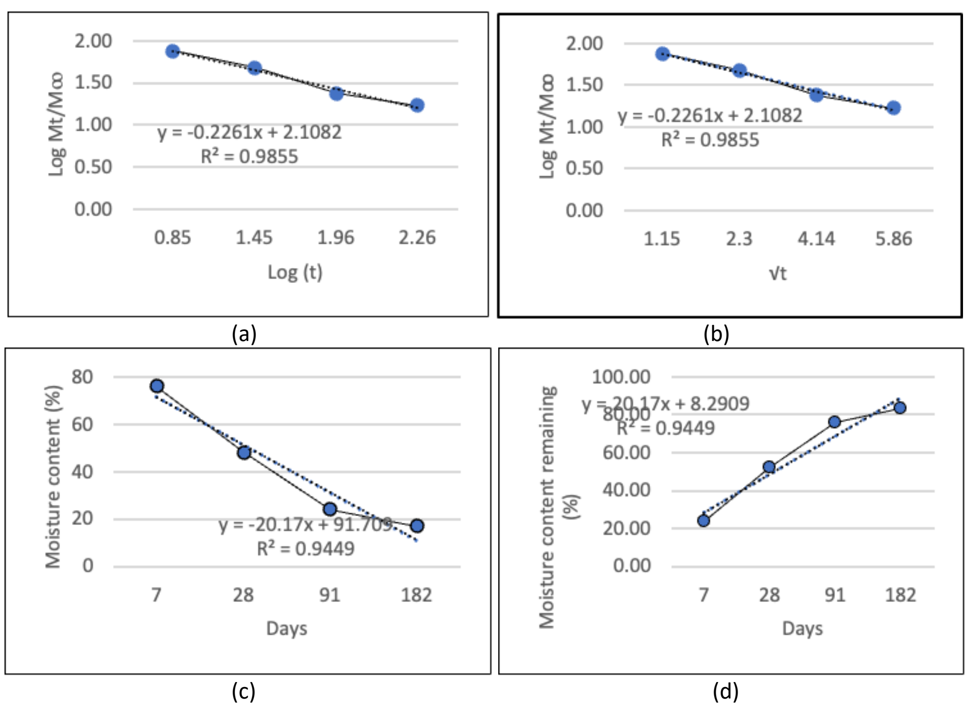


Figure 5 Kinetic models of non-equilibrium moisture of soil; (a) Korsmeyer-Peppas, (b) Higuchi, (c) zero order, and (d) first order model

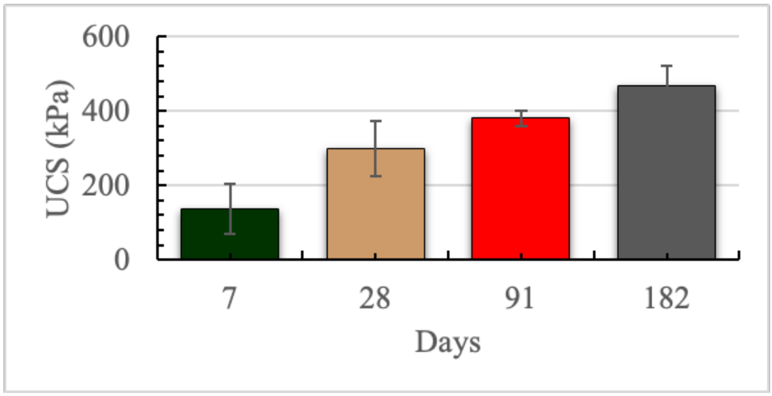


Figure 6 Effect of curing time on soil strength

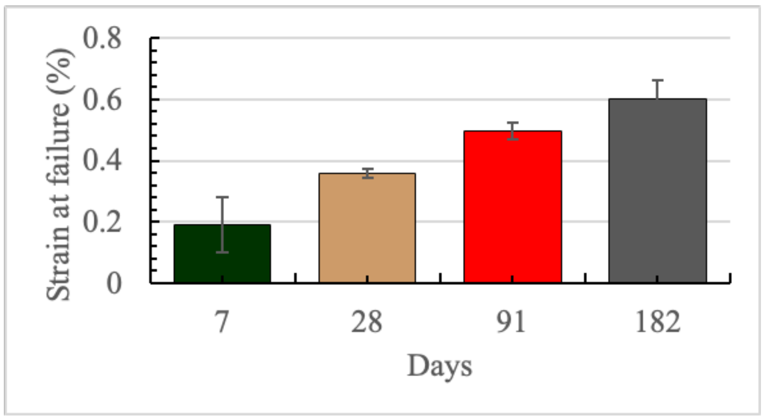


Figure 7 Effect of curing time on strain failure

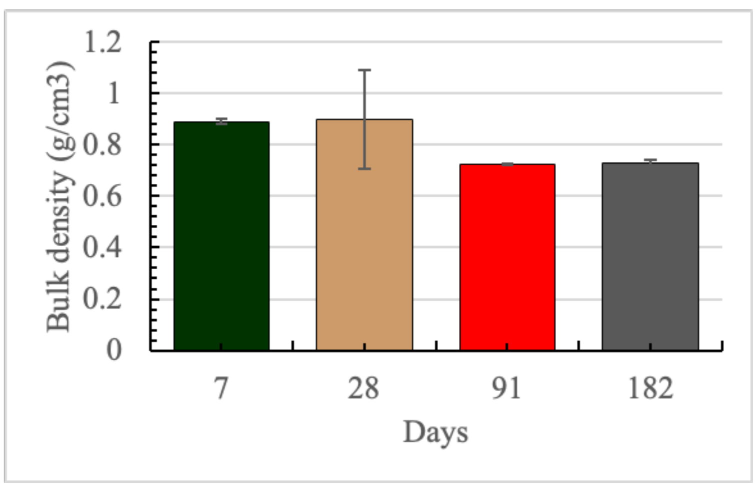


Figure 8 Effect of curing time on soil density

4.0 CONCLUSIONS

The maximum percentage of shrinkage of 26.52% was observed at 182 days of curing after applying tataki formulation. The fluctuated of pH values were observed during curing when the reaction changed from calcium hydroxide with hydrogen in soil to carbonation process. Thus, influencing the moisture content, soil strength, strain at failure as well as soil density. The filling of void by agglomeration of soil structure due to carbonation effect will influence the overall performance of peat soil throughout this study. For the future recommendation, sustainability is an important road to ensure the fulfillment of present requirements for development without compromising the resources of future requirements. The conservation of energy and resources is important for achieving sustainability in the construction sector. Sustainability in ground improvement by economizing on energy and resources ought not to cause the pollution of underground natural resources. This in agreement with Chindaprasirt et al., [17] which stated that calcium hydroxide is cost effective and has lower emission factors as compared to other materials.

Acknowledgements

The authors gratefully thank National Institute of Technology, Kagoshima College, Japan for providing the chemical in this study. The authors also acknowledged Universiti Teknologi Malaysia for financial support under UTM Fundamental Research Grant (Q.J133000.3822.22H78).

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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