Malaysian Journal Of
Civil Engineering

Full Paper

SHORT COMMUNICATION: TRENDS AND EFFECT OF CURING TIME ON APPLICATION OF MODIFIED JAPANESE FORMULATION ON LATERITE IN MALAYSIA

Article history
Received
26 April 2026
Received in revised form
01 July 2026
Accepted
06 July 2026
Published online
30 July 2026

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Abstract

Laterite can be found in many locations in Malaysia, including peninsular and west Malaysia. Despite their abundance in nature, laterites, particularly those with high clay mineral content, are very reluctant to show good strength and under load with the presence of water. As a result, their bearing capacity is also low and difficult to blend with their role in construction. Traditional Japanese techniques, especially tataki, are known for their use in floor finishes at the entrance with kneading and certain formulations for mixing. However, recently, there is an improving formulation and their adoption to clay soil in Japan. Therefore, this study proposed the implementation of a modified Japanese traditional formulation, and the effect of curing time on laterite in Malaysia. Geochemical and mechanical properties of laterite soil, including shrinkage, pH, moisture content, strain at failure, unconfined compressive strength (UCS), and bulk density, were determined. The proposed mechanism of chemical reactions was also included. Laboratory tests were conducted based on the curing effect up to 182 days. The results revealed that curing time significantly affected moisture (range 38.12-32.26%), UCS (range 156.71-1524.38kPa), strain at failure and shrinkage ($p < 0.05$) but did not influence the pH value on the laterite sample ($p > 0.05$), respectively. Kinetic study showed that the formulation followed zero- and first-order rules from low to high water holding capacity. From the study, the use of improving Japanese formulation is effective in addressing laterite soil issues and selecting the best soil formulation. Furthermore, the soil's strength improved significantly within 182 days of curing, making it suitable for utilization as a material for the improvement of soil.

Keywords: Laterite, Curing time, Modified Japanese traditional formulation, Tataki, Characteristics

1.0 INTRODUCTION

Laterite was defined by geologist, Buchanan (1807) in academic literature to describe the nature of soil in Malabar, India (Buchanan, 1807, Panton, 1956, Sivarajasingham et al., 1962, Eyles, 1970, Paramananthan & Tharmarajan, 1983, Santha et al., 2022). Laterite soil is known as the leached residue from the natural laterization process in tropical and sub-tropical areas. Laterite can be found in almost all countries around the world (Figure 1) and in Malaysia, according to Reconnaissance soil Map Peninsular Malaysia by Agricultural Department (2015), the laterite soil area is mostly found in urban land areas such as Kuala Lumpur, Melaka, Seremban, Mentakab, and Port Dickson (Rashidi et al., 2019). Laterite soil is described from a variety of angles depending on its shape, physical qualities, chemical makeup, and geological features. Panton (1956) described laterite as any iron-rich bulk in the soil profile that is typically harder than the surrounding soil and seems to have been the product of several tropical soil-forming processes. Sivarajasingham et al., (1962) elaborated laterite as significantly weathered material: (1) rich in secondary forms of iron, aluminum, or both; (2) low in humus; (3) depleted of bases and combined silica; (4) containing or lacking non-diagnostic materials like quartz; having small amounts of weatherable primary minerals or silicate clays; and (5) either hard or susceptible to hardening when exposed to alternating wetting and drying. Nuru et al. (2025) defined laterite as laterite soils, which have a characteristic reddish or yellowish color, are primarily found in settings that have experienced leaching and oxidation. Goethite, hematite, quartz, and kaolinite cemented gravels underlie these soils. It typically forms in areas of parent rock that are high in iron, silica, and alumina. A number of variables, including the parent rock's type, temperature, precipitation intensity, weathering course, bed surface characteristics, and the method of origin, can affect the qualities of laterite soil (Santha et al., 2022). In Malaysia, laterite soil has been utilized to build roads and improve rural regions. Laterite soil is used to build the subbase of highways (Mohammad and Nik, 2022, Sridhar et al. 2026). One disadvantage of adopting laterite soil, though, is that it has a high concentration of clay elements, which suggests that the soil's strength and stability under loads especially when water is present cannot be guaranteed (Ahlinhan et al. 2025). As a result, a weak subbase's bearing capability formed is usually less than the bare minimum required for road building (Mezie et al. 2025). Consequently, water or rainwater infiltration may flood the subbase, seriously damaging the road. The three primary characteristics of minerals in laterite soil are the reduction of high silica content, the primary kaolinite composition of the clay mineral, and the enrichment of the original material with aluminum, hydroxide, and iron oxide (Ali et al., 2023). Santha et al. (2022) characterized the laterite soil in general as showed in Table 1.

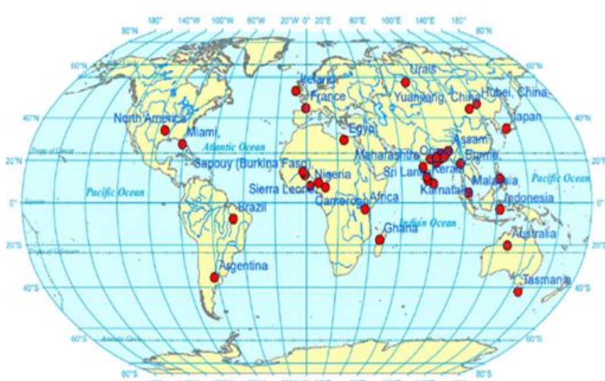


Figure 1 Laterite's location worldwide (Adopted from Santha et al., 2022)

Table 1 Geotechnical characteristics of laterite soil in general (Santha et al., 2022)

Properties	Range
Liquid limit (%)	5-75.8
Plastic limit (%)	12-48
Plasticity index (%)	8.67-36.2
Specific gravity	2.50-3.02
Optimum moisture content (%)	6.6-65
Bulk density (g/mL)	1.02-2.2
Unsoaked CBR (%)	8.5-82.8

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, the ancient Japanese practice of tataki was developed. Before cement and concrete gained popularity in the contemporary period, they were employed for ground preparation, mounding a building's foundation, and finishing flooring at entrances. A traditional farmhouse's inhabitants used a tataki floor as though it were outside to breed cattle, make meals, and carry out interior agricultural tasks. Masanori (2016) in his study prepared the tataki cube made from tataki formulation and tested on different ratio of soil. From the study, he found that tataki with granite soil secured the compressive strength of 46 N/mm^2 which is the highest strength as compared to clay soil. However, in recent years, there is re-evolution of Tataki to increase the strength and curing time. But none of them showing promising findings. Akiko et al., (2025) studied on the effect of materials on clay soil. They found that the clay soil mixed with modified tataki formulation secured the strength of more than 1000 kN/m^2. This is due to the cohesion effect of materials towards soil particles.

The percentage of clay in the soil appears to decrease as the texture of the soil changes, whereas the amount of coarse particles increases in tandem. In the presence of water, a pozzolanic reaction occurs when lime reacts chemically with clay minerals (aluminates and silicate) to form cementitious compounds known as calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which have long-term effects on strength and volume stability. The alumina and silica in the soil become more soluble as long as the high pH environment is maintained, which prolongs the pozzolanic reaction. Carbonation is the process by which carbon oxide from the air and rainwater combines with the lime to form calcium carbonate or magnesium carbonate in place of the cementitious binding chemicals. Even while some strength may be increased, the overall amount of strength gained is decreased since the cementing action is lessened. Although there has been much coverage of the aforementioned responses, many problems have remained controversial due to a lack of agreement. It is less clear, for instance, how long the aforementioned mechanisms occur over and, more specifically, whether the reaction mechanisms happen concurrently or consecutively. These problems have been the subject of a contentious debate (Asma et al., 2022). According to De Windt and Deneele (2014), cation exchange totally stops after the soil is mixed and compacted, and pozzolanic reactions begin because the hydration of lime raises the pH of the soil within a few hours. If the carbon oxide reacted with the lime, the pozzolanic and carbonation reactions might take place simultaneously. On the other hand, Diamond and Kinter (1965) proposed that instantaneous local pozzolanic reactions occur at clay surfaces as a result of lime adsorption and reaction. The intricacy of clay's nature and the potential for various mechanisms to occur in various minerals and time scales may be the cause of this discrepancy (Asma et al., 2022).

The literature on the effect of the modified tataki formulation on laterite is still scarce and as per authors' knowledge, there is no application of this formulation on laterite in Malaysia. Therefore, more research is still needed to determine how modified tataki formulation affects laterite soils especially in Malaysia. The pH values, shrinkage, moisture content, strength, density of specimens treated with the formulation at various curing times is assessed in the current study. Kinetic models were calculated for its measurement of solutions flow and chemical mechanism was proposed.

2.0 METHODOLOGY

For the methodology part, the authors started by highlighting the materials used in this study. The authors then described the methods used throughout this study.

2.1 Materials

Laterite soil was used in this study. The soils were retrieved from T05, Universiti Teknologi Malaysia (UTM), Johor prior to analysis. Lateritic soil from Universiti Teknologi Malaysia (UTM) generally exhibits high clay/silt content, with specific gravity ranging from 2.74 to 2.79. The soil typically classifies as MH or A-7-5/A-7-6 with a liquid limit of 65%–70.3% and requires stabilization, showing an OMC of approximately 28% and MDD of 1.39–1.46 g/cm³ (Wahab et al., 2021). Meanwhile, biopolymer based was used by referring to Akiko et al. (2025) study with little modification. All the chemicals which including calcium hydroxide (120g), magnesium chloride hexahydrate (200g) as well as nonionic surfactant Tween20 (0.10%) were prepared in National Institute of Technology (NIT), Kagoshima College, Japan. All the chemicals used were analytical grade. The quality of soil is maintained upon received in sealed containers. Initial pH value before adding chemicals was measured as 12.18. Then, in 2.5kg of laterite, the chemical solutions were added and homogenous the mixture gently. The mixture then compacted as specified in ASTM and AASHTO standards. The resultant samples were found 83mm in height, and 39mm in diameter, with approximately 170 g of weight. The samples produced were 12 in total with curing time was 7, 28, 91, and 182 days, respectively. The choice of curing period for this study is based on a continuation study, as well as an adaptation method from NIT, Japan.

2.2 Moisture Content Determination

The moisture analysis was conducted as mentioned in BS EN 1097-5 2008. Practically, the weight of the samples before and after incubating in the oven was determined. The temperature of the oven maintained at 105°C. The incubation is 24 hours.

2.3 pH Analysis

The pH analysis was carried out by referring to British Standard BS8601:2013. With consistency, 20g of the soils was added 50mL of distilled water. The samples were left for incubation in room temperature for 24 hours before analyzed using a sensor pH meter.

2.4 Unconfined Compression Test (UCT)

UCT test was carried out according to ASTM D2166 standard. A total of 12 samples were tested with loading rate is between 0.5 to 2.0%. The strength of formulated samples was determined.

2.5 Non-Equilibrium Kinetic Models

As this study is a non-equilibrium condition, there are four kinetic models applied in this study based on the readings from moisture analysis, which can be referred to in Table 2 (Rozo et al., 2019, Nurul et al., 2024);

Table 2 Kinetic study of water holding capacity

Models	Equations	Descriptions
Korsmeyer peppas	log Mt/M∞= k (log t)n	log cumulative percentage water holding capacity versus log time; log Mt/M∞ indicates log cumulative percentage water holding capacity log t indicates log time. “k” represents the water holding rate constant “n” refers to the flow exponent
Higuchi	ft = Q = kH (√t)	cumulative percentage water holding capacity versus square root of time kH refers to Higuchi dissolution constant “√t” is the square root of time
Zero order	Qt = k0t	cumulative amount of water holding capacity versus time

2.6 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

The resultant samples after compaction are tabulated in Table 3.

Table 3 Laterite physical properties after compaction

Curing time (Days)	Mass (g)	Diameter (cm)	Height (cm)
7	165.05±0.76	3.83±0.01	8.17±0.06
28	165.54±0.31	3.86±0.01	8.18±0.04
91	163.10±1.53	3.89±0.01	8.25±0.05
182	159.63±1.71	3.86±0.01	8.20±0.03

From table 3, the weight of the sample in general is reducing as the curing time increasing except with the weight on 28 days of curing with slightly high as compared to on 7 days of curing but the homogeneity distribution of all samples is small, indicating that the weight of all samples is almost similar. The diameter of the sample also showed same where the difference of each sample from different curing time is small and the distribution of the sample reading is homogenous from each curing time. The height of the samples also showed similar trend with diameter and the homogeneity of the reading also slightly same. In naked eye, this showed that the physical appearance of resultant samples is almost similar for all samples and the curing time is not much effect physical state of the resultant samples. One-way ANOVA revealed that the curing time has significantly affected the weight and diameter of the samples ($p<0.05$) but, less significantly affected the height of the sample ($p>0.05$).

3.1 Moisture Content Analysis

The initial moisture of laterite soil without formulation that is normally sampling in the UTM is 53.19% (Roslizayati et al., 2022). The moisture content of laterite sample in this study is depicted in Figure 2. From the figure, the moisture of the sample after curing time of 7days is slightly decreased compared to original sample (38.12%). The moisture then continued decreased from 35.81 to 32.26% on 28 to 182 days of curing, respectively. This showed that the sample has reduced their hydration process as curing time increased. One-way ANOVA showed that the curing time has significantly affected the moisture of the sample ($p<0.05$). In a similar vein, Rizal et al. (2021) showed that as the amount of lime in laterite soil increases, the moisture shows fluctuated trends where at 5% lime, the moisture is 45%, but when there is 9% lime, the moisture is below 40%. In contrast, Mohammad et al. (2022) showed their moisture is only 28%, similar to Wahab et al. (2022). Wahab et al. (2022) revealed that the loss in moisture content is due to the self-degradation of the water used during the hydration process. According to the present study, the moisture losses are perhaps due to the reaction of formulation ingredients with water as well as the binder process that causes the pore formation. As air-drying conditions were implemented during this study, the water tended to lose more. Our previous study also showed the same trend as this study (data not shown).

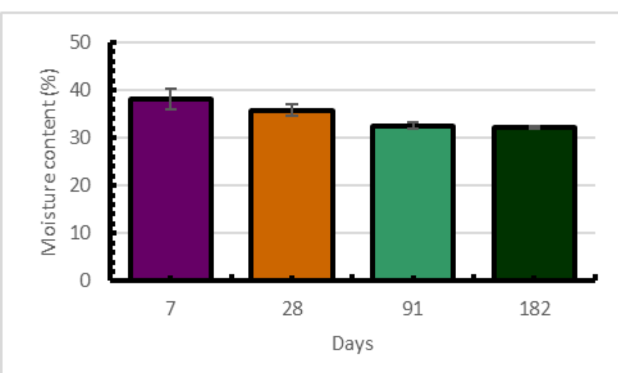


Figure 2 Effect of curing time on moisture laterite soil

3.2 pH Analysis

Initial pH of original laterite without formulation located in the UTM is more than 5 (Rizal et al., 2021, Roslizayati et al., 2022). The initial pH value of laterite after formulation with modified Japanese formulation is 12.18. The pH analysis on laterite soil in the present is shown in Figure 3. From the figure, it showed that the pH is decreased to 12.06 on 7 days of curing and 12.02 on 28 days of curing, respectively. The pH value is gradually decreased to 11.36 on 91 days of curing and increased back to 11.61 after 182 of curing time, respectively. Mohammad et al. (2022) stated that when lateritic soil is stabilized with calcium-based stabilizers like cement and lime, the pH should be raised to about 12.4 because this high pH creates an ideal environment for the formation of hydration products (CSH and CAH). Similarly, Rizal et al. (2021) found that around 2 to 3% of lime able to generate 12.8 of pH value and this alkaline pH is suitable for pozzolanic reaction. In contrast to our previous study with different formulations, laterite soil showed acidic condition.

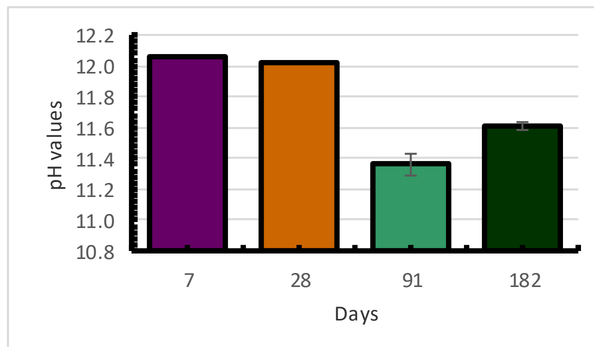
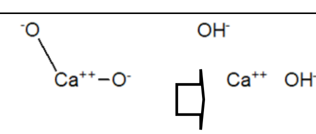
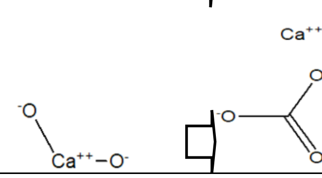
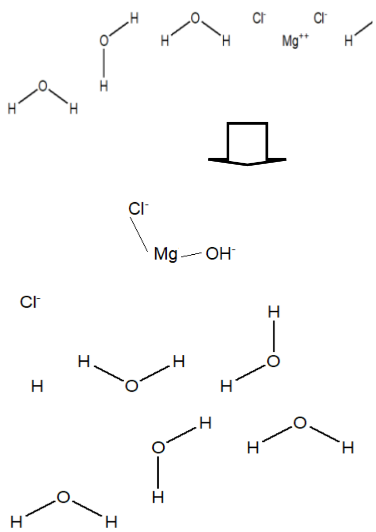


Figure 3 Effect of curing time on pH values of laterite

However, referring to this study, the increasing in pH value after formulation is perhaps due to hydrolysis process of calcium hydroxide in the formulation with water inside the laterite sample (refer to part I, Table 4a). However, after 7 days of curing, the formulation probably showed carbonation effect, thus reducing the pH value of laterite soil to 12.06 (refer to part II, Table 4b). The pH value continued to decrease to 11.36 after 91 days is perhaps due to hydrolysis process of magnesium material from formulation (refer to part III, Table 4c). On 182 days of curing, the study suggested that the surfactant in the formulation has affected the soil by increasing the pH value back.

Table 4 Chemical reaction of materials in the formulation

Table	Reactions	Process	Effect to pH
a		Hydrolysis	Increase
b		Carbonation	Decrease

c		Hydrolysis	Decrease

This finding is supported by the study Yasuo et al. (2002) which found that the pH hydrolysis of surfactant in enzyme activity of microbial is increasing from time to time. Similar study also showed by Katarzyna and Malgorzata (2014) when the pH of media increased drastically when introducing the same surfactant used in this study. However, there is no direct study reported on the effect of surfactant in laterite soil. One-way ANOVA revealed that the curing time has not significantly affected the pH of laterite soil ($p>0.05$). But it is noted that there is missing value of pH on 7 and 28 days of curing (1 reading is missing). From one-way ANOVA, the missing value is missing at random when the percentage of missing is more than 5%. T-test analysis showed that the missing pH value is significantly influenced other variables like curing time and soil strength ($p<0.05$). Estimated means from SPSS analysis suggested that all the missing pH value are perhaps 11.62. Considering the number of samples with the pH values, the authors also tested on normality test. Shapiro-Wilk test showed that all the pH value of the sample is normal distribution ($p<0.05$). One-way ANOVA revealed that the curing time has significantly affected the pH value of laterite soil.

From the proposed mechanism in table 4, it showed that the structure of water is gradually decreased as curing time increased. Therefore, referring to Figure 2, the moisture is slowly decreased as the water element decreased.

3.3 Shrinkage Analysis

The percentage of shrinkage data is presented in Figure 4. From the figure, it can be seen that the shrink on 7 days of curing is 5.22% and gradually decreased to 3.62% (28 days of curing), 2.24% (91 days of curing) and increased back to 3.03% (182 days of curing), respectively. This trend has similar pattern to the result in Figure 3 (pH analysis). This showed that the shrink is reduced as the water hydrolysis occurred during air dried but increased back when the present of surfactant reaction from the formulation. Study by Mridula et al. (2020) showed that the surfactant under room temperature has no significant changed even 24-48 hours of incubation under alkaline condition (pH = 11). However, the present of microbial activity from the soil might influence the structure of surfactant degradation (Yasuo et al., 2002). One-way ANOVA analysis showed that the curing time has significantly affected the percentage of shrinkage of the sample ($p<0.05$).

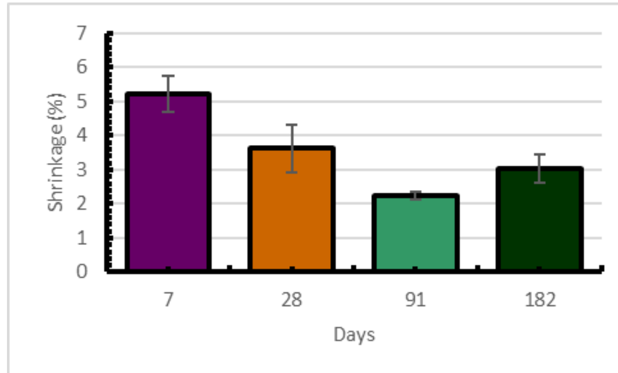


Figure 4 Effect of curing time on shrinkage of the sample

3.4 Unconfined Compression Test (UCT)

Unconfined Compression Test (UCT) results were showed in Figure 5. From the figure, it shown that the strength of soil on 7 days of curing is only 156.71kPa and the strength increased to 660.21kPa on 28 days, 1182.03kPa on 91 days, and reached the maximum of strength on 182 days (1524.38kPa). This showed that as curing time increased, the strength of soil also increased. The increasing in strength is perhaps due to carbonation and pozzolanic affect that increasing in bonding between the chemical structure, thus reducing the porosity of the sample causing high strength of soil under load (Jiang et al., 2025). This can be confirmed by the results in Table 4 (proposed mechanisms). Mohmmad et al. (2022) showed a lower UCS value (200.75 kPa), and our previous study also showed the same range as Mohammad et al. (2022). This showed that the present formulation is able to improve the soil strength significantly, and the NIT method was successfully adapted in laterite soil in Malaysia.

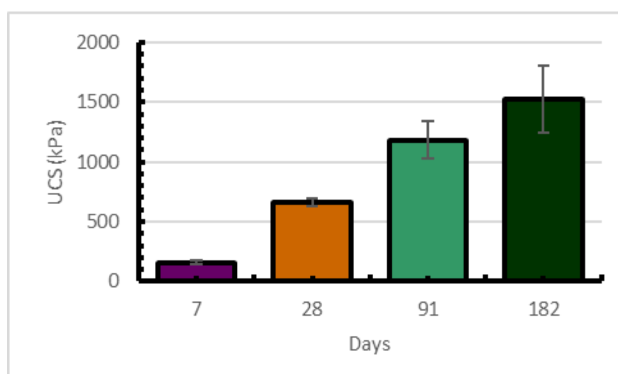


Figure 5 Effect of curing time on UCS

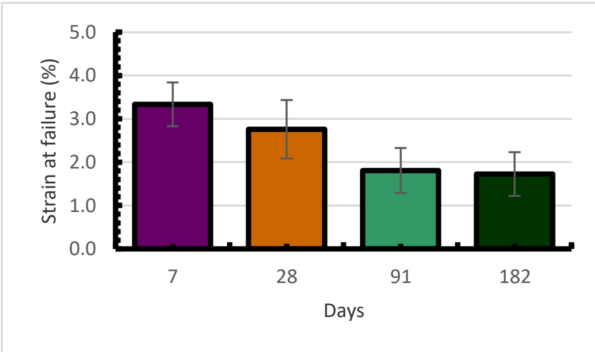


Figure 6 Effect of curing time on strain data

The results for strain analysis are depicted in Figure 6. From the figure, it shown that the strain is higher on 7 days of curing (3.33%). But the strain is slightly decreased on 28 days of curing (2.76%) and gradually decreased on 91 days of curing (1.81%), respectively. The strain showed similar trend as well on 182 days of curing (1.73%). From figure 5, it showed that as the strain decreased, the UCS is increased as curing time increased. This showed that the sample is becoming stiffer as the strength and curing time increased. One-way ANOVA revealed that the curing time has significantly affected the strain of the sample ($p<0.05$).

3.5 Density Analysis

The results for bulk density are depicted in Figure 7. From the figure, the density of the sample on 7 days of curing is higher compared to other days (1.75g/cm^3). The density on 28 days is 1.73g/cm^3, while on 91 days is 1.68g/cm^3, respectively. The trend is decreased as curing time increased. Similar to moisture content determination, the density showed gradually decreased as water content decreased. Increasing in the strength is due to chemical reaction but the void formed will influence the density of the sample (Wahab et al. 2022). One-way ANOVA analyzed this trend as significantly affected by curing time ($p<0.05$).

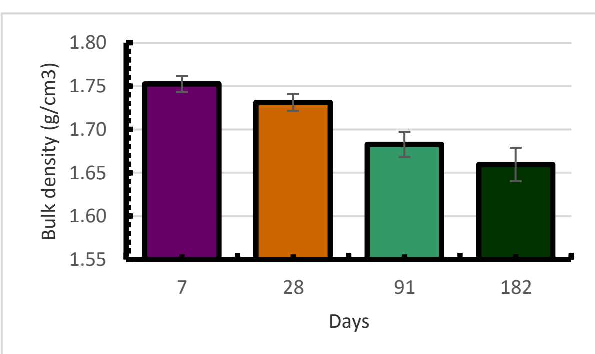


Figure 7 Effect of curing time on soil density

3.6 Kinetic study

The kinetic study revealed that this modified formulation is followed zero and first order model (R^2=0.9238) (Figure 8). It showed that as the formulation concentration decreased over curing time, the reaction also decreased. This can be confirmed by the mechanisms structure proposed in Table 4. It showed that the reaction ~~is~~ gradually decreased as the degradation of the structure increased.

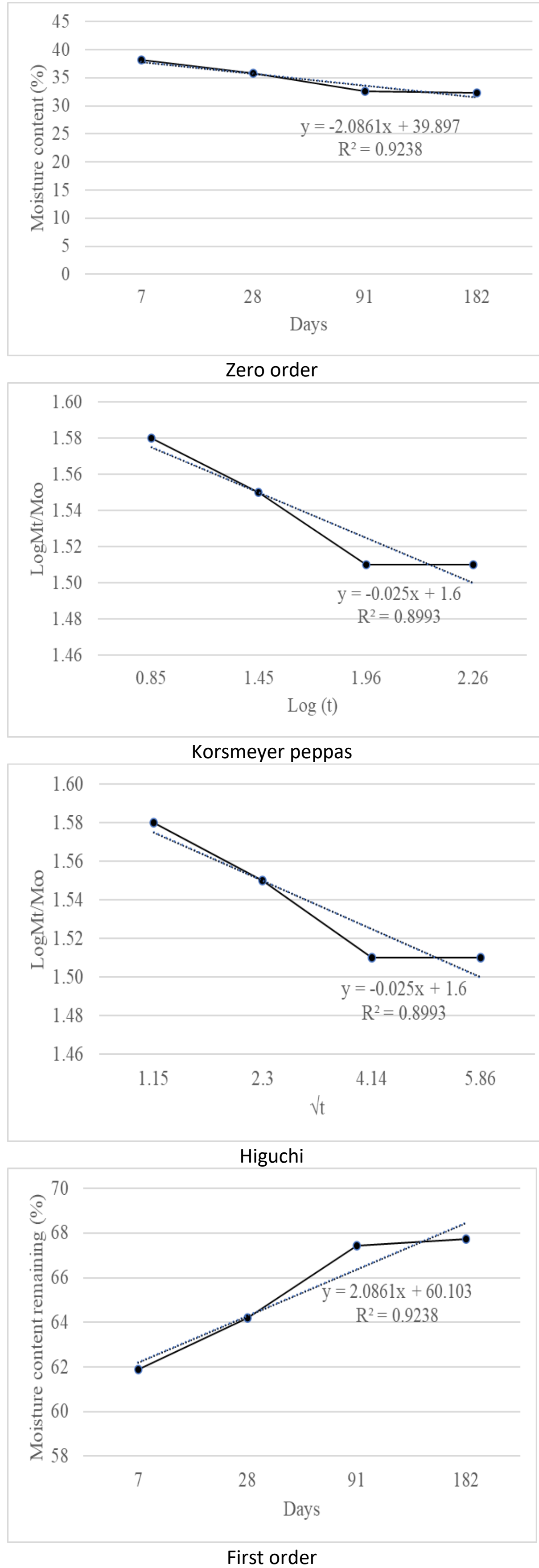


Figure 8 Kinetic study of water holding capacity flow

4.0 CONCLUSIONS

As conclusion, from this study, the moisture is decreased as curing time increased and the pH showed decreasing in the first 91 days of curing but increased back on 182 days due to reaction with surfactant. The shrinkage also showed similar trend like pH value with supported the assumption that there is another reaction of surfactant from formulation in the soil instead of carbonation and hydrolysis of calcium and magnesium. UCS analysis revealed that the strength increased as curing time increased and in contrast the density showed opposite trend to the strength. Kinetic study is finally supported the findings on chemical reaction when showing the trend that followed zero and first order model indicating that the concentration decreased and there is degradation of materials occurred as curing time increased. From this study, the modified Japanese formulation is greatly adapted to laterite soil in Malaysia. The curing time also influence the moisture, UCS, strain at failure as well as bulk density of the soil.

Acknowledgements

The authors gratefully thank Universiti Teknologi Malaysia and Faculty of Civil Engineering for research support. Further thanks are given to National Institute of Technology, Kagoshima College, Japan for providing biopolymer solutions.

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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