Experimental Study on Mechanical Behavior of Laterite Soil Treated with Quicklime

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ABSTRACT

The present study examines the effect of lime stabilisation on the mechanical properties of laterite soil. Compaction tests were performed in order to obtain optimum moisture content (OMC) and maximum dry density (MDD) for untreated and lime treated laterite soil. A series of Unconfined compressive strength (UCS) tests were carried out on the specimen containing different percentages of lime. In preparing test specimens, laterite soil was initially compacted at their respective OMC and MDD conditions and allowed to cure for 0, 3, 7, 14 and 28 days before being tested. Results for the standard compaction test show an increasing trend for optimum moisture content (OMC), whereas maximum dry density (MDD) decreased as the concentration of lime increased. On the other hand, UCS results indicated that all percentages of lime treated laterite increased in strength with the curing period.

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Introduction

Laterite soil is found abundantly in hot and wet tropical regions such as Malaysia. Generally, laterite is rich in iron and aluminium and was formed by geological processes through tropical weathering. According to [1] and [2], the colour range for laterite soil starts from light and ends with bright to brown shades, and the presence of iron oxides makes laterite soils reddish in colour. Laterites have become one of the most reliable materials used in civil engineering construction as fills or pavement materials due to their widespread availability in massive amounts. However, the lateritic soil used for infrastructures such as railways and roads construction material may not be stable, particularly under severe rainfall conditions [3]. Given this issue, stabilisation of lateritic soil plays a key role in the stability of infrastructures.
Stabilisation of problematic soil is essential to avoid costly construction failure in engineering. Sufficient information about the method of improvement is necessary for geotechnical application. Cement, calcium chloride, lime, gypsum, fly ash, sodium chloride, bitumen, and sodium silicate are among the chemical soil treatments used today to improve engineering properties and soil performance. [4]-[8]. The effectiveness of these additives depends on the soil types and the amounts of additives used for soil improvement. For instance, those soil stabilisers that work well in tropical regions may be less efficient when applied to soils in more moderate regions [9].

Cement is the most widely used an additive utilised for soil stabilisation, but it does have some drawback in term of environmental/sustainability when large volumes of cement are used for large-scale stabilisation projects [10]. Lime is widely used in developing countries to stabilise soil because it is affordable, low cost [11] and simple compared to other stabilisers [12]-[13]. Additionally, lime is considered one of the best stabilisers for enhancing the engineering properties of soft soil, and it is used globally [14]-[16]. Lime is the stabilising agent that improves soils' strength and stiffness properties and reduces their swell–shrink potential. Due to chemical reactions, finely divided clay particles agglomerate into coarser particles, resulting in improved load-bearing properties [17].

Lime treatment that influenced the strength in soil properties is generally referred to as soil modification that is controlled by quick reaction and soil stabilisation which depends on pozzolanic reactions [18]-[19]. When lime is added to laterite soil, the reaction between dissolved silica and alumina with calcium present in lime allows the soil to develop a durable and stable bond particle. Long-term pozzolanic reactions produce cementitious products such as calcium-silicate-hydrates (CSH) and calcium-aluminate-hydrates

(CAH), which are similar to the cementitious products found in Portland cement, causing a long term improving the strength and stiffness of lime-stabilised soil [19]–[21]

Hydrated lime is often used to improve the engineering properties of tropical soils as road work materials in previous studies [22]. Therefore, current study aims to explore the effectiveness of quicklime as a stabiliser for laterite soil in terms of mechanical behaviour. To assess the physical properties of laterite soil, several laboratory tests were conducted, including moisture content, Atterberg limit, particle density, and particle size distribution. Besides, for mechanical behaviour, standard compaction and unconfined compression strength (UCS) tests are further discussed to evaluate the strength of lime treated laterite soil.

Material and Method

Laterite soil used in this research was taken from site at the University Teknologi Malaysia campus (UTM), southeast Malaysia. The sample was manually excavated from a disturbed state in sufficient amounts to complete the test. Laterite soil was air-dried and sieved through a sieve with a 2 mm opening for all lab purposes.

Quicklime was adopted as the stabiliser in this test. The main intention was to evaluate the suitability of laterite soil to be stabilised with lime. Table 1 presents the basic soil properties according to British Standard (BS) 1377: 1990.

Table 1: Basic properties of laterite soil

Properties	Values
Natural moisture content (%)	53.19
Specific gravity of laterite	2.79
Specific gravity of quicklime	3.25
Liquid limit, LL (%)	65
Plastic limit, PL (%)	46
Plasticity index, PI (%)	19
Soil Classification	MH (sandy SILT)
Maximum dry density (g/cm^3)	1.37
Optimum moisture content (%)	31
Unconfined compressive strength (UCS) kPa	194
Undrained shear strength kPa	97

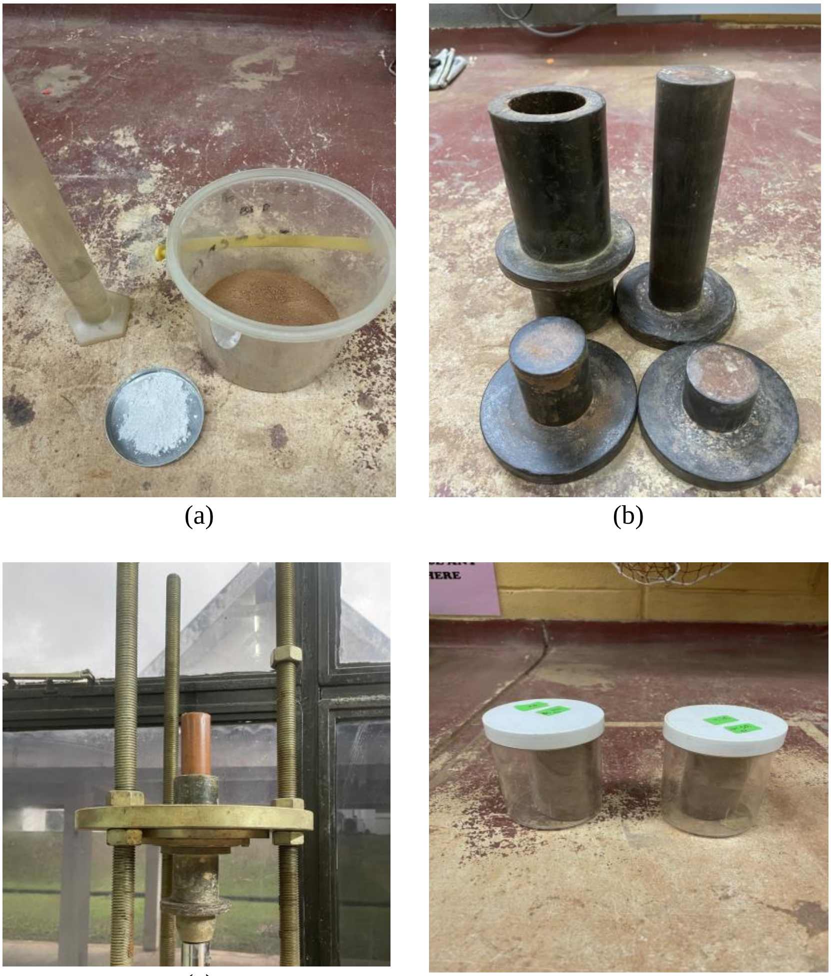
The Initial Consumption Lime (ICL) test was conducted by mixing oven-dried soil containing various percentages of lime (2-10%) with 100 mL of distilled water to obtain an aqueous solution. The solution is stirred at regular intervals and left for at least 8 hours. Then, the pH is measured for each by using a pH meter. By plotting pH value versus lime content, lime content corresponding to pH value 12.4 is stated as optimum lime concentration.

Standard compaction tests were carried out on stabilised soil with variable concentration of lime content. Five samples at varying percentages of quicklime (0, 3, 5, 7 and 9%) by dry weight were prepared. Samples were mixed until they became a thoroughly homogeneous mixture, and without delayed, the sample was compacted in three layers at 27 blows using 2.5 kg weight of the hammer. After compaction was conducted, an amount of soil was taken for moisture content determination, and the compacted samples were trimmed to remove excess soil and weighed for bulk density. The lime content and curing condition of the specimens are tabulated in Table 2.

The mixtures were compacted into a cylindrical mould with a diameter of 38 mm and a height of 76 mm The mixtures were compacted into three layers. The contact surface between each layer was scratched after each layer was compacted to ensure that the soil remained intact. The sample was extruded using a compression extruder, trimmed, wrapped with plastic, and placed in the bottle for the final sample preparation step. The samples are then cured in a humidity chamber (27± 2 ºC) for the required curing period before testing. The sample preparation stages are shown in Figure 1. The soil sample was subjected to UCS testing at a constant strain rate of 0.5 mm/min until soil failed or reached a maximum strain of 15%.

Table 2: UCS testing plan

No	Quicklime (%)	Curing days
1	0	0
2	3	0, 3, 7, 14, 28
3	5	0, 3, 7, 14, 28
4	7	0, 3, 7, 14, 28
5	9	0, 3, 7, 14, 28



(a) (b)

(c) (d)

Figure 1: Sample preparation; a) admixture, b) mould, c) hydraulic compressor, and d) sample for curing

Result and Discussion

ICL refers to the amount of lime required to attain a pH of 12.4, as well as visible changes in soil properties, plasticity, and compaction, and the ability to activate the pozzolanic reaction [23]. Figure 2 shows the result for Initial Consumption Lime (ICL). Lime's percentage above ICL results in a pozzolanic reaction, leading to enough cementitious products. Figure 2 shows that adding 5% lime resulted in a pH of 12.4, which is the minimum amount required to satisfy cation exchange reactions. [24]. Based on studies by [25], The appropriate dose of lime for soil stabilisation is typically between 2% and 8% of the dry weight of the soil. A lime range of 1 to 3 percent is generally required for soil modification, whereas a lime range of 2 to 8 percent is required for actual stabilisation [26]. Reduction in soil plasticity occurs during soil modification, and cementation product or pozzolanic reaction may occur during actual stabilisation. Optimum Lime Content is essential in lime stabilisation to improve workability, reduce plasticity and increase strength, durability and stiffness [27].

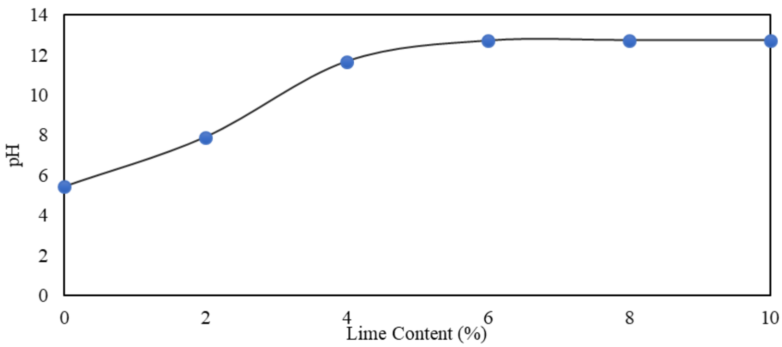


Figure 2: pH test results for different lime content

Figure 3 illustrates the effect of lime on the compaction curve for treated and untreated laterite. As observed in Figure 3, optimum moisture content (OMC) increased from 30.63 to 35.24 after lime was increased from 3% to 9%. In contrast, maximum dry density decreases as the percentages of lime increased. The grain size increases due to the cation exchange and flocculation process, leading to a high void ratio and decreased in maximum dry density value while increasing the optimum moisture content [28]. According to [29], the increase in OMC is due to high lime-water bonding, which causes portlandite to dissociate and produce Ca2+, which is responsible for the cation exchange reaction. The results obtained are consistent with [7], [30], and [31]. The overall trend for optimum moisture content and MDD with different lime content is illustrated in Figure 4.

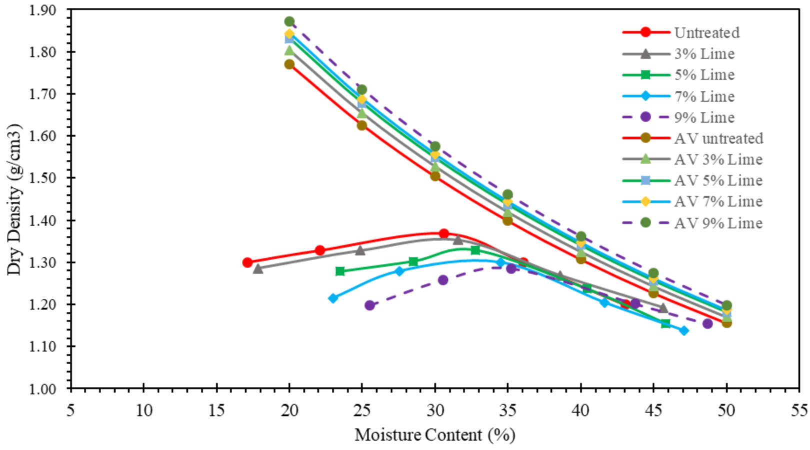


Figure 3: Compaction curve of untreated laterite and lime – laterite soil

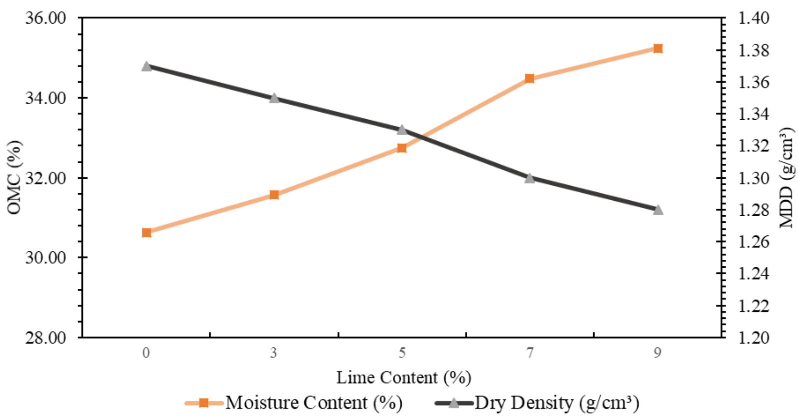


Figure 4: Overall trend for optimum moisture content and MDD with different lime content

Figure 5 illustrates the lime-treated sample's stress-strain response with different curing days. For reference, the UCS result for the untreated sample, which is 194 kPa also shown in Figure 5. The time-dependent pozzolanic reaction is responsible for the continuous increase in compressive strength observed in UCS tests with longer curing days [32]. Figure 5 shows that as the curing period is increased, the UCS values rise while the associated axial strains at failure decrease. The decrease in the strain at peak strength showed that the soil becomes stiffer over time. The peak stress was minimum for the untreated sample, but it shows an obvious peak at maximum compressive strength (q_u) due to the absence of confining stress. This behaviour is considered a strain-softening trend in which the stress decreases after reaching its maximum value [8]. It was observed that laterite soil mixed with 5% lime shows the highest strength compared to other percentages until 14 days of curing time (Figure 5d). The UCS value of untreated soil increased by 511, 583.34, 550.43 and 525 kPa for addition of lime content from 3, 5, 7 and 9%, respectively. It can be explained that calcium ions in lime improved the result for compressive strength of treated soil. The 3% lime added to soil slightly increased after curing for 28 days to 591 kPa compared to other percentages (5, 7 and 9%), which rapidly increased to 705, 758.67 and 741.02 kPa. This shows that 3% lime is not enough to stabilise the lateritic soil. Overall, the finding of this study are consistent with those of previous research studies [33]–[36].

It can be concluded that, for given curing conditions, the soil will achieve maximum strength at the optimum lime content. In contrast, it will not produce a significant strength increase below that optimum lime content. As seen in Figure 6, specimens cured for a long time showed a significant increase in strength resulting in the formation of cementitious products as a result of pozzolanic reactions as time was prolonged [37]. Figure 6 shows that the UCS of treated soil increases as the curing time increases. The results are consistent with the previous study [38]. Cementitious product will be developed after pH value greater than 12.4. If lower dosages of lime are used, it may be not sufficient to increase the pH up to 12.4 to release silica and alumina from soil to allow for stabilisation. As shown in Figure 7, this could be the cause of the slightly lower compressive strength with 3 percent lime. As depicted in Figure 7, the UCS increase with increasing lime content up to 5%. Beyond 5% lime, the increase of UCS at 28-days curing is negligible, and even the UCS at curing time lower than 28-days decreases with increasing lime content more than 5%. Therefore, it is inferred that 5% lime is the optimum value for treating the lateritic soil used in this study. The results achieved for the UCS trend upon lime increment are compatible with the previous study [39]. Adding lime to the laterite soil triggers the pozzolanic reactions occurring between Ca2+ contain in lime with silica and alumina in laterite, resulting in cementitious products such as calcium silicate hydrate (CSH) and calcium alumina hydrate (CAH). These new compounds alter soil structure and increase soil strength [13], [40]

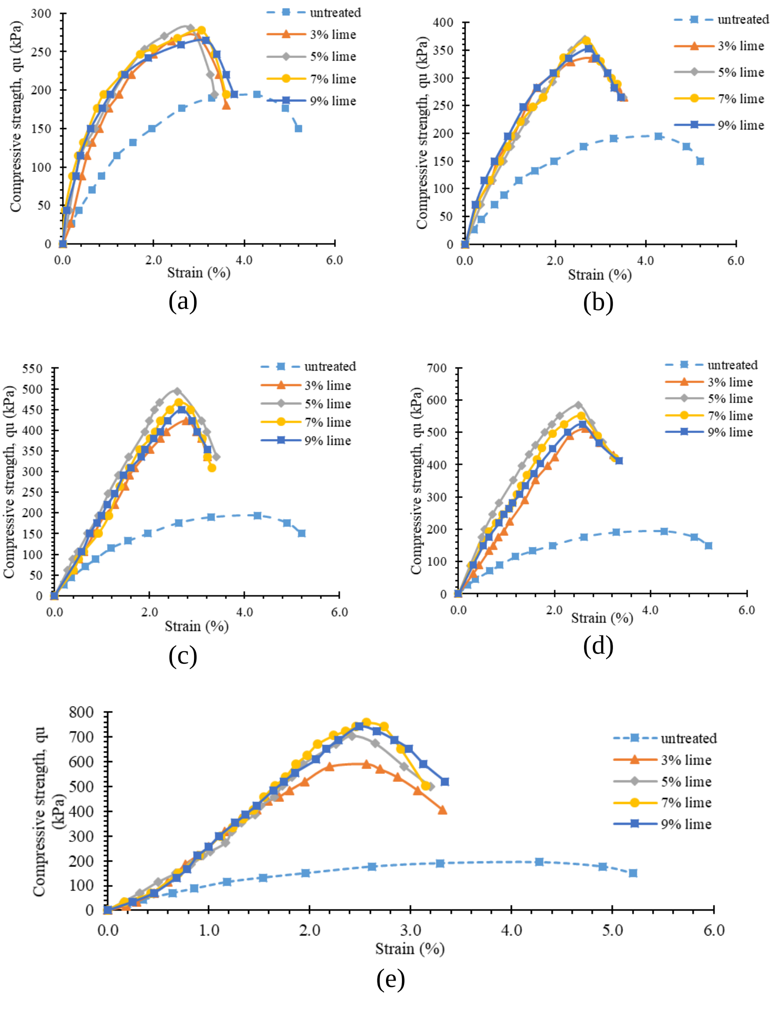


Figure 5: UCS results for different curing period; (a) 0 days, (b) 3 days, (c) 7 days, (d) 14 days, and (e) 28 days

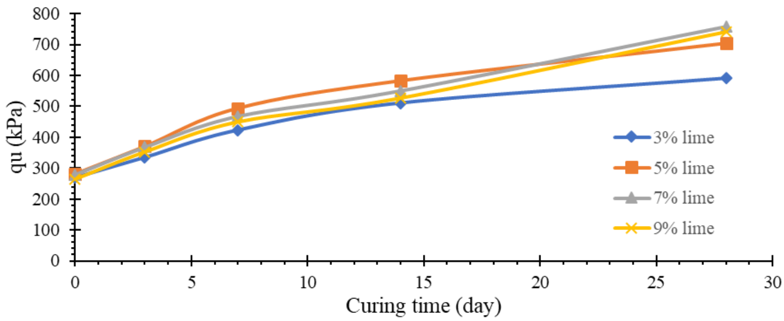


Figure 6: Relationship between UCS with curing time for different lime content

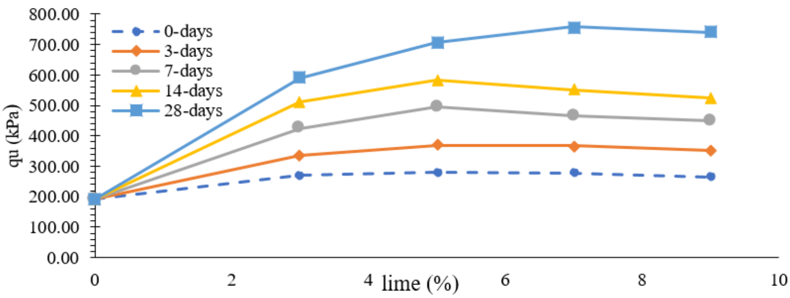


Figure 7: Relationship between UCS and lime content for different curing period

Conclusion

Laboratory investigations of stabilised laterite soil with lime were conducted to explore the compaction behaviour and the improved performance in mechanical behaviour of treated soil based on different curing days. Based on the test results, the specific conclusion can be made as follows:

i. Compaction test results indicated that adding lime content significantly increased the optimum moisture content (OMC) of treated sample while the maximum dry density (MDD) reduced due to agglomeration and flocculation of particles soil resulting in large pore spaces.

ii. The lime added to laterite soil has a significant effect on improving compressive strength on different curing days. This issue thus confirmed that pozzolanic reaction occurred between lime and laterite that bind the soil particle together, resulting in strength improvement.

iii. According to compressive strength curves, 5% lime is the optimum lime content to stabilise the lateritic soil used in this study effectively.

Overall, the findings of this study show that using lime as a soil stabiliser can improve the mechanical properties of laterite soil. Hence, lime with optimum content can be selected as a suitable stabilising material for geotechnical engineering purposes.

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