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Effect of surcharge load on Microbial-Induced Calcite Precipitation (MICP) treatment of tropical peat

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Abstract. Peat is known as problematic ground with low bearing capacity and extensively high compressibility. Ordinary Portland cement (OPC) and lime were usually used to tackle unfavourable characteristics of peat by improving it with its cementation effect. However, little was known of the effect of bio-cementation towards peat improvement. Bio-cementation or commonly known as Microbial-induced calcite precipitation (MICP) has been recently introduced as a ground improvement alternative for geotechnical engineering application. MICP performed by utilising metabolic pathways of non-pathogenic urealytic bacteria that precipitates calcium carbonate (CaCO_3) crystal as cementation binder that seal soil particles together increasing soil strength. MICP of inorganic soil was extensively explored, and only limited was done for organic soil. This study explores on the effect of different surcharge preloading of 18kPa, 36kPa and 48kPa towards Microbial-Induced Calcite Precipitation (MICP) treatment of tropical peat. Fibrous peat studied were obtained from Miri, Sarawak and cured under a submerged condition with different vertical preload for seven days. Laboratory study including unconfined compression test, quantification of carbonates precipitated, and moisture content of stabilised specimens was observed to evaluate the performance of stabilisation effort. Unconfined compressive strength (UCS) of treated specimens was observed to be higher than untreated specimens with the highest increase of UCS up to 469%. However, CaCO_3 precipitation amount for this study was observed to decrease with increasing surcharge preload.

1. Introduction

Tropical lowland peatlands covered approximately 23 million hectares in Southeast Asia with the most extensive coverage situated in the coastal zone of Southeast Asia, especially in the countries such as Indonesia and Malaysia. Malaysia has peatlands cover of approximately 2.6 million hectares with Sarawak state covering the most significant extent of peatland over 1.6 million hectares represent approximately 70 per cent of peatlands in the country [1, 2]. Peatland construction is usually unfavourable with its poor bearing capacity, low permeability, high compressibility with high creep rates and often difficult accessibility [3, 4]. Peat stabilisation can be done through chemical method including deep mixing and surface stabilisation along with chemicals additives or binders [5, 6]. Portland cement or lime was commonly used for such efforts promoting cementation in peat [7, 8].



Limited study was done for the effect of bio-cementation as an alternative for peat stabilisation. Bio-cementation or known as Microbial-induced Carbonate Precipitation (MICP) works by bio-precipitation of carbonate crystal on soil materials bridging soil particles and sealing void leading to improvement of engineering [9]. The microbial mechanism was based on hydrolysis of urea by urealytic organism followed with the introduction of calcium (Ca^{2+}) ions into the environment leading to calcite (CaCO_3) precipitation [10, 11]. Shear strength (cohesion and friction angle) and unconfined compressive strength (UCS) of bio-cemented soil was shown to be improved compared to control [12-14]. MICP as emerging soil improvement method has been widely studied for inorganic soil [15-20]. Flushing with cementation reagents of constant flow rate or surface percolation and soaking methods commonly practised for MICP treatment on soil bio-cementation [21-23]. The objective of this study is to evaluate the effect of the different surcharge load towards MICP of peat after seven days curing under a submerged condition in the laboratory. Cementation reagents containing calcium chloride (CaCl_2) as Ca^{2+} sources and urea were added, and urease activity was depended on indigenous urease activity of peat. Unconfined compression test was performed to evaluate strength development, and calcium carbonate precipitation was also quantified for stabilised peat specimens of three different surcharge rates - 18kPa, 36kPa and 48kPa in 7 days.

2. Methodology

2.1. Materials

The peat samples were collected in Miri, Sarawak, Malaysia. The disturbed soil was collected in bulk and stored in containers sealed to prevent any moisture loss or gain. The properties of the used peat in this study were characterised following ASTM D4427 [24] and subsequently presented in Table 1 below.

Previous study makes use of exogenous bacteria as urease source. Urealytic non-pathogenic bacteria such as *S. pasteurii* and *B. megaterium* were introduced to the target soil to induce urea hydrolysis to facilitate bio-cementation mechanism [11, 25]. The previous study has shown the presence of urealytic microbial sources in tropical peat [26, 27]. Hence, indigenous urease activity of peat was considered as sole urease source for this study.

Table 1 The basic characteristic of peat used for the study.

Properties	Natural peat
Natural moisture content (%)	700 - 800
Fibre content (%)	50 - 60
Organic content (%)	94 - 96
Ash content (%)	4 - 6
pH	4.9
Von Post Designation	H3 - H5
Specific gravity	1.23

2.2. Specimen preparation

Roots and coarse fibres from wet peat were removed followed by wet sieving passing through 2 mm sieve. The peat slurry was homogenised with kitchen mixer to ensure that uniform moisture distribution throughout peat matrices. For each specimen, 500g of the peat slurry was mixed with 100 mL of pre-sterilized cementation mixtures containing both urea (60.06 g) and CaCl_2 (110.98 g). For untreated specimens, peat slurry was mixed with 100 ml of distilled water. The peat slurry mixture was homogenised for 5 minutes with kitchen mixer to ensure that uniform moisture distribution before being pour into PVC tube with a size of 50 mm internal diameter and 260 mm height with porous stone covering both ends. Wet curing for soft soil stabilisation simulating saturated field condition was performed [28, 29].

The tubes were placed vertically submerged in water with different surcharge load of 18kPa, 36kPa and 48kPa for both treated and untreated specimens. The specimens were cured for seven days before

performing the Unconfined Compression Strength (UCS) Test. All the treated and untreated samples were prepared in duplicates.

2.3. Method of testing

The stabilised specimens were extracted from the PVC pipe and cut to 100 mm height with a ratio of 1:2 with the diameter. UCS test was performed following ASTM D2166 [30] under the maximum of 500 N load cell by using Universal Testing Machine with the loading rate of 2.0 mm/min. The unconfined compressive strength recorded as the peak stress of the soil stress-strain curve or is identified as peak stress correspond to vertical strain reaches 20% as described by a previous study [31]. The moisture content of the untreated and untreated specimens was obtained according to ASTM D4427 [24]. The specimens were rinsed with distilled water to remove excess CaCl_2 , and urea on soil particles before CaCO_3 precipitation of the samples was estimated based on acid wash method described by Heiri, et al. [32].

3. RESULTS AND DISCUSSION

Figure 1. shown reduction of the moisture content of the treated samples compared to untreated samples correspond to the same surcharge preload curing. This is due to the presence of urea hydrolysis which consumes water producing carbonates ions while increasing the pH of the soil environment [33]. The moisture content of soil greatly affects soil stability and its strength [34, 35]. Increased of surcharge preload during curing produces specimens with lower moisture content while increasing preload contributes to the consolidation of peat specimens and speed up water discharge [36]. Carbonates content were not present in untreated specimens. Figure 2. showed that calcium carbonates (CaCO_3) precipitated were decreased with increasing surcharge preload. The trend suggested that relative density may affect calcium carbonate precipitation. Increasing consolidation due to higher surcharge load may increase the bulk density of curing peat. A previous study on inorganic soil showed that more calcium carbonate precipitation occurs in soil with lower relative density [37].

The study were observed with overall higher unconfined compressive strength (UCS) of the treated sample compared to untreated (Figure 3.). Highest UCS was observed at 17.19 kPa for specimens cured at 48kPa preloading compared to 8.31 kPa obtained by treated specimens cured under 18kPa surcharge preload. Although it was observed that treated has shown higher strength compared to untreated under the same respective surcharge loading, however the magnitude percentage of strength gain between treated and untreated was highest with specimens cured under lower surcharge load of 18kPa followed by 36kPa and 48kPa with 469%, 425% and 457% respectively. These may be due to decreasing CaCO_3 precipitation that affects bio-cementation of peat particles. Hence, this may suggest that increasing UCS values between treated and untreated were due to consolidation with increasing preload and CaCO_3 precipitated has also contribute to strength gain.

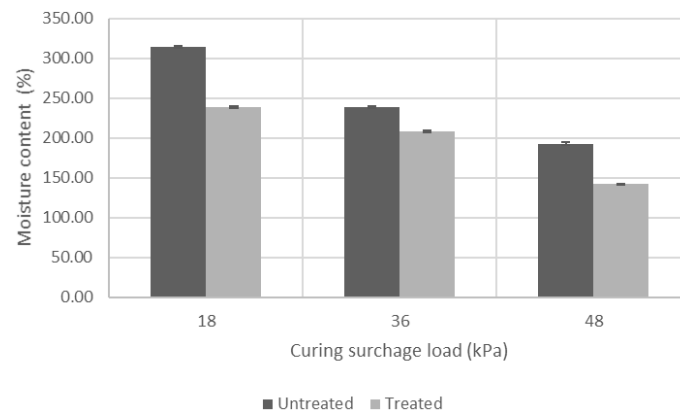


Figure 1. Moisture content changes compared between Untreated and Treated Samples after cured for seven days under a submerged condition with different surcharge preload.

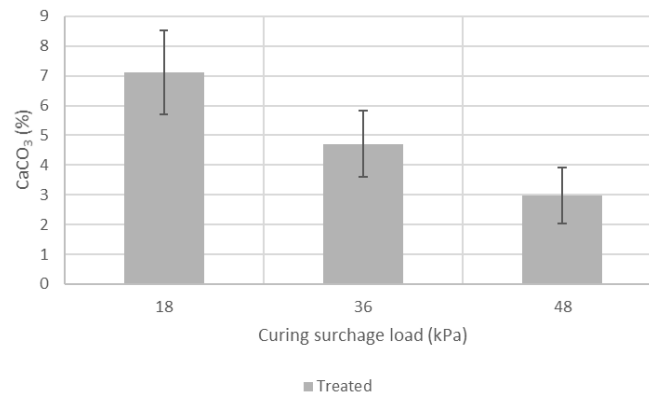


Figure 2. Calcium carbonates (CaCO₃) precipitated in the Treated Samples after cured for seven days under a submerged condition with different surcharge preload.

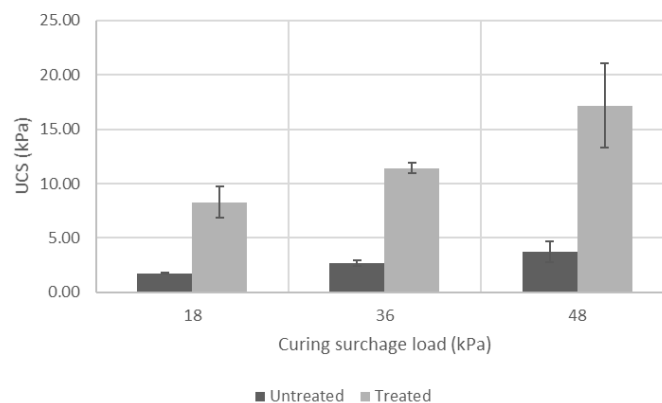


Figure 3. Unconfined compressive strength (UCS) of Treated and Untreated samples after cured for seven days under a submerged condition with different surcharge preload.

4. Conclusion

This study concluded that overall unconfined compressive strength (UCS) of the treated peat specimens (shown with CaCO₃ precipitation) were higher compared to untreated specimens (without CaCO₃ precipitation). Although it was observed that increasing surcharge load has decreased CaCO₃ precipitation, compressive strength of the treated specimens was observed to be higher than untreated

specimens with less CaCO_3 when cured under the same surcharge load. The results suggested the potential of bio-cementation in peat stabilisation and future study are required.

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