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Effectiveness of Chloride Salts on the Behaviour of Lime-Stabilised Organic Clay

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ABSTRACT: The presence of organic matter, in particular humic acid, is one of the most important factors affecting the effectiveness of lime stabilisation of clays. In this paper, an investigation on the effects of humic acid and chloride salts on the strength of lime-stabilised organic clay is presented. Different humic acid contents of 0.5%, 1.5% and 3.0% were mixed with kaolin prior to the stabilisation with 5%, 10% and 15% hydrated lime. The strength of the lime-treated organic clay was analysed using the Unconfined Compression Strength (UCS) tests at different curing periods of 7, 28 and 90 days and further verified by microstructure analysis. The results showed that a significant strength loss was obtained beyond 1.5% humic acid content and the strength was diminished at longer curing periods. However, by adding 0.5% chloride salts, the behaviour of lime-treated specimens with 1.5% humic acid content was successfully improved.

Keywords: Humic Acid, Organic Clay, Stabilisation, Hydrated Lime, Chloride Salts.

1. INTRODUCTION

Numerous studies focused on lime stabilisation of soils have been published in literature and the application of this technique has seen much advancement in civil engineering practice and research [1], [2], [3] and [4]. In contrast, lime stabilisation of organic clay has always faced a complex outcome in the long term due to the presence of high concentrations of organic matter [5], [6], [7] and [8]. It has been reported that more than 1% humic acid content in clay may render the lime stabilisation process ineffective [9], [10], and [11]. Therefore for organic soils, lime alone may not be effective or even sufficient as a stabiliser. It should be pointed out that the amount of humic acid present in organic soil does not correspond to the type of organic soil. In fact the type of organic soil (e.g. peat, gyttja) is often defined based on the total content of organic matter. However, some organic compounds do not have any detrimental effect on the cementing reactions. Thus, it is vital, to quantify the amount of humic acid that renders lime stabilization inefficient.

One way of mitigating the adverse effects of humic acid is by introducing a small amount of chloride salts (e.g. $CaCl_2$ or NaCl) to lime-treated organic clay. The idea of adding admixture to lime-treated clay is to provide additional cations (i.e. Ca^{2+} and Na^{+}) to promote ion exchange activity and dissolution of clay minerals such as silica and alumina for pozzolanic reactions. These reactions are thought to enable greater development in shear strength of organic clay, especially in the long term [9], [12], [13].

This paper presents an experimental study on the behaviour of lime-treated organic clay with various humic acid contents. In addition, the influence of 0.5% $CaCl_2$ and 0.5% NaCl on the behaviour of lime-treated organic clay is investigated. Changes in soil's microstructure due to the addition of chloride salts were also examined by Scanning Electron Microscopy (SEM).

2. MATERIALS

Artificial organic clay used in this study was prepared by mixing commercial kaolin with 0%, 0.5%, 1.5% and 3% commercial humic acid contents according to the dry mass of kaolin. The chemical elements present in each soil mixture are listed in Table 1.

Table 1. Chemical elements in the tested soils.

Element	Wt (%)			
	0%HA	0.5%HA	1.5%HA	3.0%HA
C	2.12	2.8	2.74	20.16
O	47.91	50.45	54.54	48.97
Na	0.2	0.36	0.41	0.81
Mg	0.64	0.65	0.64	0.56
Al	19.43	16.94	18.47	12.8
Si	26.71	24.74	21.52	14.07
P	0.09	0.18	0.28	0.16
S	0.02	0.05	0.12	0.42
Cl	0	0	0.01	0.19
K	2.65	3.42	0.79	0.59
Ca	0.02	0.02	0.04	0.33
Ti	0	0	0.02	0.18
V	0	0	0.01	0.01
Fe	0.21	0.39	0.4	0.74

In general, the effect of humic acid on the chemical composition of clay can be detected from the increase in carbon and oxide ions. As a result, the increase in amounts of carbon and oxide ions and the decrease in silica and alumina contents can be observed with increasing humic acid content, as shown in Table 1.

The results of Index Testing carried out on inorganic and organic clays are summarized in Table 2. All of the tested soils were suitable to be stabilized by lime as the Plasticity Index (PI) was more than 10.

Table 2. Physical properties of clay with different humic acid contents.

Property	Humic acid content (%)			
	0	0.5	1.5	3
Liquid limit (%)	65.4	64.4	63.6	61.0
Plastic limit (%)	30.4	33.0	33.8	34.5
Plasticity index (%)	35.0	31.4	29.8	26.5
Specific gravity	2.61	2.53	2.51	2.47
pH	5.52	5.34	5.16	5.07
OMC (%)	30.6	30.9	30.6	33.4
MDD (kg/m^3)	1440	1429	1425	1404

3. SPECIMEN PREPARATION

Specimens tested in this study were prepared using procedures described in the ASTM standard D5102. Initially, the specimens were oven-dried at 60°C until the constant weight was obtained. Clay with different amounts of humic acid was prepared by mixing relevant amounts of dry kaolin with 0.5%, 1.5%, and 3% of humic acid by dry mass of kaolin. Mixing of dry materials was continued until a uniform appearance of the kaolin-humic acid mixture was obtained. Distilled water was then added and further mixing was performed until a homogeneous appearance of the soil paste was achieved. This paste was then used for plasticity and compaction tests.

Similarly, predetermined quantities of each additive (i.e. lime and salts) were derived based on the dry mass of soil solid and mixed until homogenous mixture was obtained. This material was then mixed with water according to the optimum moisture content (OMC). The mixing process progressed until a homogenous consistency of moist paste was achieved. Mixing was conducted as quickly as possible to ensure that lime was not exposed for too long to air. This was necessary to avoid carbonation process which could affect the strength performance of treated samples. The minimum quantity of lime required for stabilisation of the organic clay was found using the Initial Consumption of Lime (ICL) test. Furthermore the amount of lime added to the organic clay with addition of salts was taken at optimum lime content (OLC), as discussed later on. The percentages of salts ($CaCl_2$ and NaCl) added to the lime-treated organic clay were 0.5%, 2%, and 5%, respectively.

All the specimens (76 mm in height and 38 mm in diameter) were compacted into the mould, extruded from it and wrapped in cling film to preserve the water content and to keep them free from carbon dioxide (CO_2). The specimens were then cured in a desiccator at 20°C and with humidity of more than 90% for 7, 28, and 90 days, respectively. Most of the time, a single test was performed for each mixture. However, selected duplicate and triplicate samples were first tested to ensure repeatability of testing data.

4. RESULTS

The results of a short term strength assessment of lime-treated clay with different humic acid contents (0%, 0.5%, 1.5%, 3%) and lime contents (5%, 8%, 10%, 15%) are shown in Fig. 1.

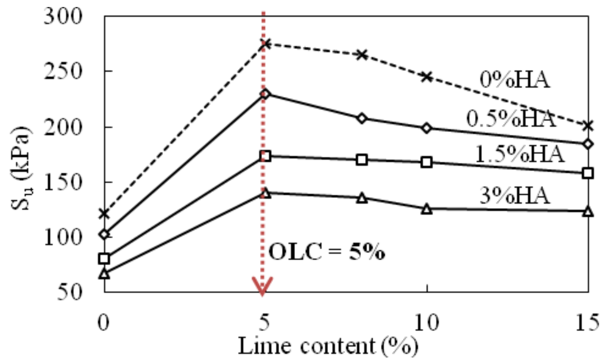


Figure 1. Effect of lime content on the undrained shear strength of clay with different humic acid contents after 7 days of curing.

All the specimens were cured for 7 days. It can be seen from Fig. 1 that the undrained shear strength (S_u) of the specimens with 5% lime content increases significantly compared to the strength of untreated clay (i.e. 0% lime). However, the shear strength of specimens with higher than 5% lime content reduces gradually with increasing lime content regardless of the humic acid content in the clay. Therefore, 5% was taken as the optimum lime content (OLC) for each type of organic clay. Fig. 1 also shows that the shear strength of organic clay decreases with increasing humic acid content, which proves that the presence of humic acid in organic clay diminishes its shear strength.

In a further assessment of the effect of humic acid on lime stabilisation, samples were tested at 0, 7, 28, and 90 days to ascertain the duration of the stabilisation process. Since the OLC of each specimen was identical, investigation of the development of the lime-clay reaction with time was conducted only for 5% lime content. Fig. 2 illustrates the development of the shear strength of the lime-treated specimens at 0, 7, 28 and 90 days. It appears that with the exception of the inorganic clay (0% humic acid) the undrained strength of the lime-treated clays comprising 0.5%, 1.5% and 3% humic acid decreased over 90 day curing period. A slight loss in the strength is observed for organic clay with 0.5% humic acid, while substantial loss in strength is evident where the humic acid content is equal to or greater than 1.5%.

The results demonstrate that lime stabilization of organic clay with a high humic acid content is not very efficient in the long term. Similar observations were reported by other researchers [8], [9], [10] and [11]. It should be noted that despite exhibiting a loss in strength in the long term, the undrained strengths of lime-treated samples at 90 days were still higher than those of untreated specimens (see Fig. 1 for 0% lime). However, for practical purposes, it is not feasible to consider lime stabilisation as successful when the long term shear strength is uncertain.

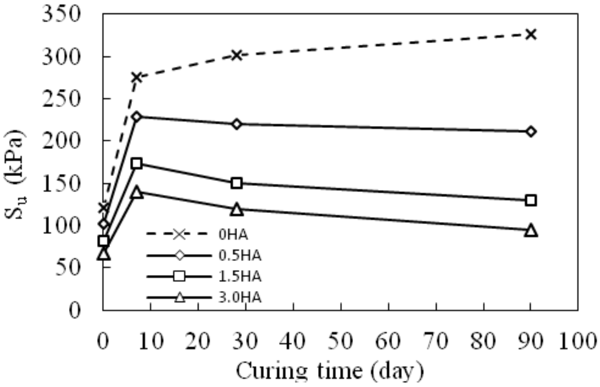


Figure 2. Effect of curing time on the undrained shear strength of lime-treated clay.

The impedance in the formation and development of cementitious products with increasing humic acid content over longer curing periods may be due to various reasons.

Firstly, the reduction in pH value at longer curing periods may be one or the reasons for decreased shear strength values. Fig. 3 shows the pH value of various humic acid contents treated at OLC = 5% for different curing periods.

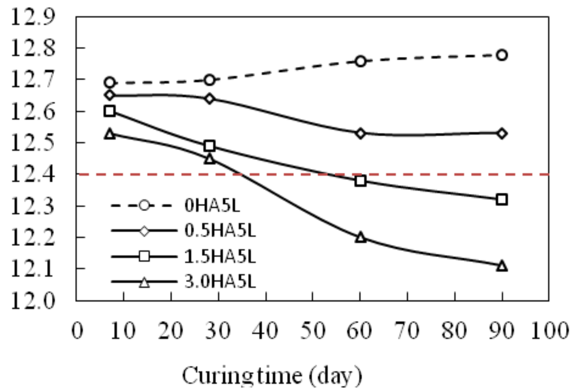


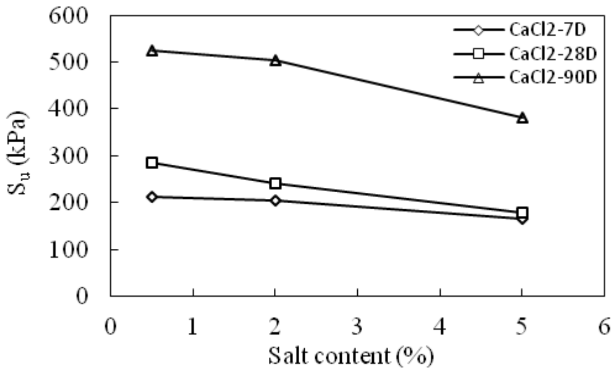
Figure 3. Effect of curing period on pH value of lime-treated organic clay with different humic acid contents.

It can be seen from Fig. 3 that, except for inorganic clay, the pH values of all the clay specimens decreased with increasing curing period. After 35 and 55 days, specimens with 1.5% and 3% humic acid contents respectively, had pH values lower than 12.40, which is the minimum required for successful production of cementing materials [14].

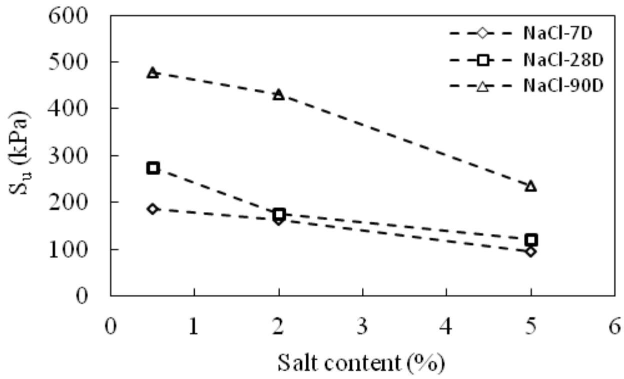
Secondly, bearing in mind that the dissolution of clay minerals is highly dependent on pH value, it is thought that the presence of a certain amount of humic acid made it difficult for the solution to recover from its acidified condition. Humic acid may have coated the clay particles, thereby preventing the lime from coming into contact with clay minerals during the pozzolanic reaction. Consequently, the dissolution of clay minerals became insufficient, thus limiting the production of cementitious materials.

The findings obtained from the experiments on lime-treated organic clay revealed that lime may not be suitable for stabilising organic clay with more than 1.5% humic acid content [15]. Therefore, two chloride salts (calcium chloride ($CaCl_2$) and sodium chloride (NaCl)) were considered as potential additives to improve the effectiveness of lime stabilisation in organic clay. The analysis was carried out for the clay with 1.5% humic acid content stabilised with 5% lime.

Fig. 4 shows development of the undrained shear strength with increasing salt content for different curing periods.



(a)



(b)

Figure 4. The influence of salt content on the undrained shear strength of lime-treated organic clay at different curing periods: (a) $CaCl_2$; (b) NaCl.

Fig. 4 shows a clear increase in S_u as the curing period increases from 7 to 90 days for both types of salts. However, for increasing salt content, the measured S_u decreased for both types of salt. This is in contrast to other studies which reported a shear strength increase with increasing salt content [9], [12] and [13].

In this study, the highest S_u was measured for 0.5% chloride salt content. Therefore, 0.5% was assumed to be the optimum salt content (OSC) for both types of chloride salts. This observation is in agreement with previous studies suggesting that only small quantities of salts are effective for the strength enhancement of lime-treated specimens [14], [15] and [16].

Fig. 5 shows development of S_u with 0.5% $CaCl_2$ and NaCl for different curing periods. The salt-treated specimens are also compared to those treated by lime alone (i.e. 0% salt content) at corresponding curing periods. A clear increase in the strength can be noted for both types of salt as the curing period increases from 7 to 90 days. Overall, the strengths recorded for the lime-$CaCl_2$ mixtures were higher than those for the lime-NaCl mixtures [14]. A similar finding was reported by [17]. It could be because of the dual function of Ca^{2+} ions promoting better ion exchange and contributing towards the formation of cementing products (i.e. calcium silicate hydrate, CSH and calcium aluminate hydrate, CAH). The Na^+ ions, on the other hand are only believed to accelerate silica dissolution [9], [14] and [17].

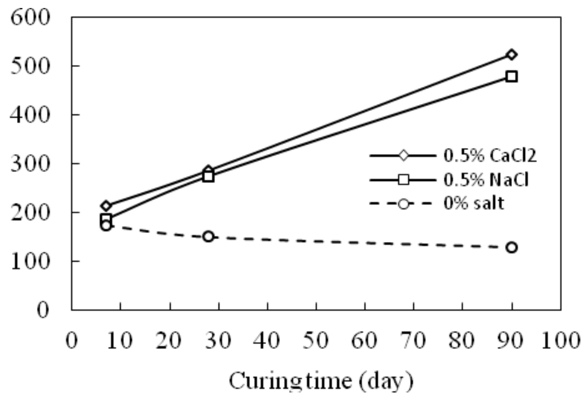


Figure 5. Effect of 0.5% chloride salts on the undrained shear strength of lime-treated clay at different curing periods.

In this study, microstructure analysis of selected specimens was also carried out using Scanning Electron Microscopy (SEM). Selected SEM micrographs are presented in Figs. 6 to 8. Fig. 6 shows the image of a lime-treated specimen with 1.5% humic acid content without any salt additives. The changes in soil structure due to lime stabilisation were hardly visible. The microstructure of the specimen was very similar to that of a specimen without lime [18].

Figs. 7 and 8 show selected SEM images of lime-treated organic clay with the addition of 0.5% chloride salts. The micrographs were taken from UCS test samples after 28 curing days.

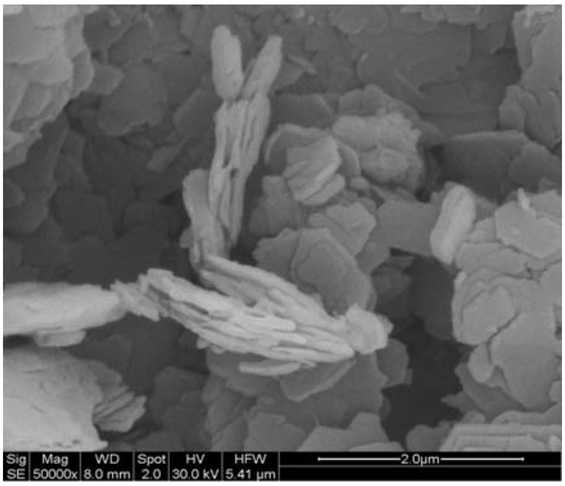


Figure 6. SEM image of lime-treated clay with 1.5% humic acid and without salt additives.

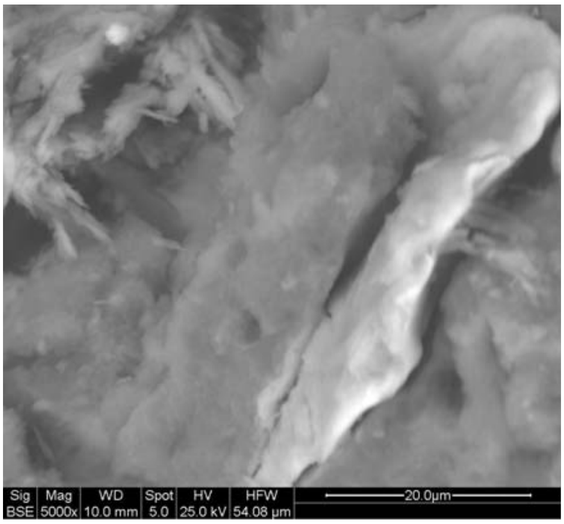


Figure 7. SEM image of lime-treated clay with the addition of 0.5% $CaCl_2$ after 28 days of curing.

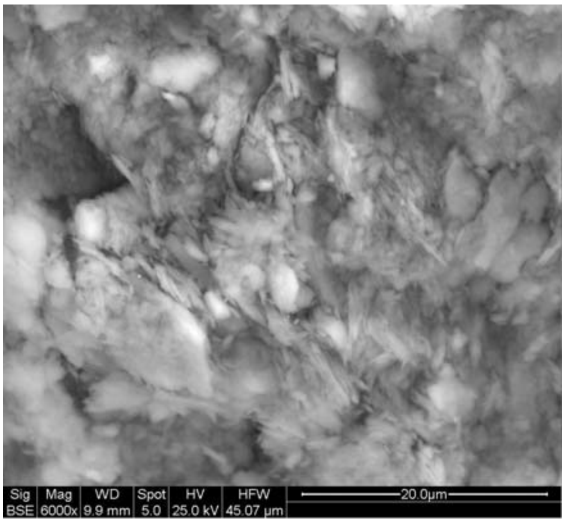


Figure 8. SEM image of lime-treated clay with the addition of 0.5% NaCl after 28 days of curing.

It can be seen from Figs. 7 and 8 that the flaky and plate-like structure present in the lime-treated organic specimen (Fig. 6) has almost completely disappeared. A clear cemented structure, mainly calcium silicate hydrate (CSH), was identified to bridge all the aggregates [14], [18]. The presence of these cementitious structures in specimens with the addition of salts explains the improvement of the undrained shear strength of lime-treated organic clay.

5. CONCLUSIONS

In this paper, the effectiveness of lime stabilisation of organic clay was investigated. In addition, a preliminary investigation on the effect of salts on the strength of lime-treated organic clay was carried out. Based on the experimental results obtained in the study, the following conclusions can be made.

1. The shear strength of lime-treated organic clay reduces when the lime content exceeds 5%. Thus, 5% of lime is identified as the optimum lime content (OLC) for the organic clay tested in this study.
2. The shear strength of the lime-treated organic clay reduces at longer curing periods. A slight loss in the strength is observed for organic clay with 0.5% humic acid, while a substantial loss in strength is evident where the humic acid content is equal to or greater than 1.5%. These results show that the presence of more than 1.5% humic acid in the organic clay tested in this study reduces significantly the efficiency of the lime stabilisation process.
3. The results obtained from the UCS tests carried out on specimens with 1.5% humic acid treated with 5% lime show that the strength of lime-treated organic clay can be successfully improved with addition of 0.5% chloride salts. Therefore, there is a potential for using chloride salts in lime stabilisation of organic clay in geotechnical practice.
4. Scanning Electron Microscope (SEM) images of lime-treated organic clay show the flocculated and aggregated structure, without appearance of cementation. In contrast, a clear evidence of cemented structure is observed when lime-treated organic samples are stabilised with addition of 0.5% $CaCl_2$ and 0.5% NaCl.

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