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Research Paper

Effects of Sugar Mill Lime Sludge Treatment on the CBR and UCS of Expansive Soil in Bukidnon

Cheryl F. Daleon[1*] & Glen A. Lorenzo[2]
[1]Department of Civil Engineering, College of Engineering, Central Mindanao University, Musuan, Bukidnon 8710, Philippines
[2]Department of Civil Engineering, Mindanao State University-Iligan Institute of Technology (MSU-IIT), Iligan City, Philippines

ABSTRACT

The purpose of this study is twofold: to address the proper utilization and disposal of a locally available industrial waste known as sugar mill lime sludge, and to determine whether it could improve the subgrade performance of an expansive clay by evaluating its California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). The expansive soil known as Adtuyon clay from Stockfarm, Dalwangan was treated with lime sludge contents of 0%, 5%, 10%, 15%, 20%, 25%, and 30% (all by dry weight of soil); the specimens from each of these mixing conditions were cured at 0, 7, 14, and 28 days. Results show that the treated soil with 10% lime sludge and curing period of 28 days demonstrated a higher CBR and UCS. On the other hand, treated soils with lime sludge contents above and below 10% regardless of curing periods have indicated lower CBR and UCS values, thus yielding inferior engineering properties. Therefore, the expansive clay in Bukidnon can be stabilized using the locally available sugar mill lime sludge at an optimum lime sludge content of 10% cured at a minimum curing period of 28 days.

Keywords: Adtuyon, CBR, Expansive soil, Lime sludge, UCS

INTRODUCTION

Expansive soils are widely distributed in the world and found in more than 60 countries and regions. The problem of expansive clay is a worldwide issue according to Muntohar (2006). During road construction, it is of paramount importance that the expansiveness is adequately identified. The design engineer needs to address the influence of expansive soils both as naturally occurring undisturbed soils and as the compacted, in-situ or borrowed soils used in the road formation. It is necessary to identify the source of expected heave or shrinkage before selecting the design solution. Failure to correctly identify these soils and adopt appropriate engineering design could lead to failures and costly remedial works (O'Connell & Gourley, 1993).

Based on the soil map generated by the Bureau of Soils and Water Management (BSWM), large areas of soil cover in Bukidnon are dominated by Adtuyon clay. This clay is known as an expansive soil. Moreover, the national highway in the province mainly traverses along this type of clay wherein significant defects on surfaces were observed along this stretch of national highway over the last two decades. These defects could be attributed to the swelling properties of Adtuyon clay which usually leads to costly repair since the soil is not properly treated prior to road construction.

Dhakar and Jain (2016) stated that the prob-

*Corresponding author: Cheryl F. Daleon; E-mail: cheryl_daleon@yahoo.com.ph

lem might be overcome by proper structural design, but it needs expansive efforts to estimate the expected stresses in the component and subsequently designing it. They added that the better option is to improve engineering properties of these soils by suitable stabilizing techniques. Improving an onsite soil's engineering properties is called soil stabilization (Kulkarni, Padalkar, & Joshi 2017). Common stabilization methods are by application of suitable materials or recycled waste such as cement and fly ash and injection of suitable grouts. The most widely used method is applying lime to the soil in order to improve its engineering properties. Krithiga, Pujitha, Palayam, and Revathy (2017) stated that lime stabilization is a method of chemically transforming unstable soils into structurally sound construction foundations. Lime stabilization is particularly important in the construction of a highway for modifying subgrade soils, subbase materials, and base materials. The improved engineering characteristics of materials which are treated with lime provide important benefits to Portland cement concrete (rigid) and asphalt (flexible) pavements.

Aldaood, Bouasker and Mukhtar added that the chemical soil stabilization technique by lime is presented as a tried and tested technique for strength development of the soil. However, the lime application is not sustainable in the long run since lime is a limited resource and constant mining of lime could lead to environmental degradation. One of the possible replacements for lime in soil stabilization is the by-product of paper and sugar milling companies, and water treatment plants called lime sludge, which is already being considered in various engineering applications. Lime sludge has the same composition as limestone, but it is softer. In Bukidnon, the lime sludge from BUSCO Sugar Milling Company is currently not being utilized for its possible application to geotechnical engineering. This waste is just being abandoned in huge amount and dumped along roadsides in Butong, Quezon, Bukidnon. Some of these materials sometimes end up in streams and rivers which can be seriously hazardous to the environment and human health. Thus, investigating the possible application of sugar mill lime sludge as a substitute to commercially available lime to improve the engineering properties of the soils in Bukidnon is very helpful to ensure the safe disposal and utilization of this kind of a waste.

METHODOLOGY

The soil samples were taken from six different locations in Bukidnon at (1) Mt. Kitanglad, Impasug-ong, (2) Stockfarm, Dalwangan, (3) Laguitas, Malaybalay, (4) Lurugan, Valencia, (5) Musuan, Maramag, and (6) Camp 1, Maramag. Figure 1 shows the soil map with the six sources of soil, where the red portion and white line represent the Adtuyon clay and national highway of the province, respectively.

The samples used were taken from about 1 m from the ground surface to minimize the contents of organic matter in the soil. The six soil samples were sent to a laboratory for determination of Atterberg Limits via Fall Cone Method in order to determine the most expansive soil among the samples. It was found out that the soil from Stockfarm, Dalwangan, Bukidnon gave the largest plasticity index (PI) of 30.01 %, which indicated highly expansive characteristic since it exceeded a PI requirement of 25% (by ASTM D4318) that may cause swelling and pavement problems. About 500 kg of the soil was obtained from Stockfarm Dalwangan, Bukidnon and was air-dried to be used for treatment and testing. About 60 kg of lime sludge from BUSCO Sugar Milling Company was air-dried, noting that once dried, lime sludge can easily be crushed into a fine powder. The air-dried soil and the lime sludge were then pounded to a finer grain and then sieved through #10 sieve to make sure that the samples were more or less in the same size. Afterward, the sugar mill lime sludge was added to the dried soil samples at 0% (untreated), 5%, 10%, 15%, 20%, 25% and 30% (all by weight). The samples were indexed based on the percentage amount of lime sludge added to the soil as shown in Table 1. S100L0 means 100% soil and 0% lime sludge, S95L5 has 95% soil and 5% lime sludge and so on.

The air-dried soil and lime sludge samples passing sieve #10 mesh were sent to Holcim Philippines in Lugait, Misamis Oriental for XRF analysis in order to determine its chemical compositions.

About 28 samples of 6 kg each of soil-lime sludge mixtures were prepared to determine the California Bearing Ratio. A different compacted specimen of soil-lime sludge mixtures were cured for 0, 7, 14, and 28 days respectively. After curing, the mold was placed in the soaking tank for four days. After soaking, the CBR tests were

Figure 1. Soil Map of Bukidnon from Bureau of Soils and Management

Table 1

Soil-lime Sludge Mixtures

Index	Soil (kg)	Lime Sludge (kg)
S100L0	6.0	0.0
S95L5	5.7	0.3
S90L10	5.4	0.6
S85L15	5.1	0.9
S80L20	4.8	1.2
S75L25	4.5	1.5
S70L30	4.2	1.8

conducted based on ASTM D1883 -Standard Test Method for CBR of Laboratory-Compacted Soils. On the other hand, for the UC test, about 28 soil-lime sludge samples approximately 1200 g each were prepared. The specimen of soil-lime sludge mixtures were carefully extruded from the tube and cured for 0, 7, 14, and 28 days respectively. The test was based on ASTM D 2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soil.

RESULTS AND DISCUSSIONS

Engineering Properties of Expansive Soil

Table 2 shows the Atterberg Limits of Adtuyon clay from six different locations in Bukidnon. The corresponding liquid limit of the Adtuyon clay from Stockfarm Dalwangan is equal to 65.17 %, and the plastic limit is 35.16% that gave a plasticity index of 30.01%. A liquid limit value of greater than 60% means that the soil has a high potential to swell (Das, 2002). PI values determined the corresponding degree of expansion categorized by IS 1498. The overall geotechnical index properties from Atterberg limit and grain size analysis of natural Adtuyon clay from the said location showed that it could be classified under the A-7-5 subgroup with group index (GI) of 37 of the AASHTO Soil Classification System and OH (organic clay of high plasticity) in the Unified Soil Classification System. A higher GI means a poorer material. It was dark yellowish brown clay, fine-grained, the maximum particle size is ½ inch, 0.07% gravel, 3.28% sand and 96.64% passing sieve no. 200. It was an organic silty clay, poorly graded, and highly plastic. Geotechnical investigations on various kinds of soils showed that clays of high plasticity were likely to be highly expansive, more compressible and consolidate over a longer period of time under load than clays of low plasticity.

X-ray Fluorescence (XRF) Analysis of Adtuyon Clay and Lime Sludge

Table 3 shows the various chemical composition of Adtuyon clay and lime sludge from XRF Analysis. Pozzolanic clay contains reactive silica and/or alumina which on their own have little or no binding property. However, when mixed with lime, in the presence of water, it will set and harden like cement. XRF analysis of Adtuyon clay showed that its major components were Silicon Dioxide and Aluminum Oxide, which made it reactive with lime. Loss on Ignition (LOI) which was almost half of silica or alumina indicated the content of organic matter in the soil. Organic matter reduced the load carrying capacity of the soil.

As expected, the major component of lime sludge was Calcium Oxide which was almost half of its weight. The high percentage of Loss on Ignition (LOI) which was almost equal to the calcium content of lime sludge indicated that the sample contained a high amount of organic materials. Minor Elements which include Si, Al, K,

Table 2

Atterberg Limits of Adtuyon Clay from Different Location in Bukidnon

Source of Adtuyon Clay	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index(%)	Degree of Expansion based on IS 1498
Mt. Kitanglad, Impasug-ong	64.97	40.23	42.74	High
Stockfarm, Dalwangan	65.17	35.16	30.01	High
Laguitas, Malaybalay	54.66	38.10	15.56	Medium
Lurugan, Valencia	60.12	40.07	20.05	Medium
Musuan, Maramag	53.51	33.78	19.73	Medium
Camp 1, Maramag,	62.63	38.41	24.22	High

Na, and Fe were also detected.

Hart (1993) conducted a study about the chemical composition of typical lime sludge as an engineering material. The chemical composition and engineering properties of 20 samples of lime sludge, produced from the lime calcining process, were determined in order to evaluate its potential applications as an engineering construction material. Because of its high natural water content, low density, and poor strength characteristics, lime sludge in its natural state is considered unsuitable for engineering construction. However, when lime sludge was mixed with varying percentages of a silty soil, it was found out that the density of the admixtures increased and the permeability decreased with an increase in soil content. This suggests that lime sludge-soil admixtures may have the potential for such engineering applications as daily landfill cover, hydraulic barriers, and structural fill material. Adding lime in the soil to increase its strength is called lime stabilization. Bell (1989) identified two stages of lime stabilization. The first stage involves ion exchange on the surfaces of clay minerals (to produce calcium clays) while the second stage is the removing of silica (and some alumina) from the clay mineral lattice. The initial exchange and chemical attack produce a gel which hardens that forms an interlocking structure. Lime stabilization also increases the strength of all clayey soils, increases their permeability, increases their erosion resistance, and markedly increases their volume stability against swell and shrinks.

California Bearing Ratio (CBR)

The CBR rating was developed for measuring the load-bearing capacity of soils used for building roads. Shingloo (2016) stated that the harder the surface, the higher the CBR reading. A CBR of 3 equates to tilled farmland, a CBR of 4.75 equates to turf or moist clay, while moist sand may have a CBR of 10. High quality crushed rock has a CBR over 80. The standard material for this test is crushed California limestone which has a value of 100.

Effect of Sugar Mill Lime Sludge on the CBR of the Treated Soil

The stronger the subgrade (the higher the CBR reading), the less thick it is necessary to design and construct the road pavement, which gives a considerable cost saving. Conversely, if CBR testing indicates that the subgrade is weak (a low CBR reading), a suitable, thicker road pavement should be constructed to spread the

Table 3

Chemical Composition of Adtuyon Clay and Lime Sludge by XRF Analysis

Chemical composition	Adtuyon clay	Lime sludge
Silicon Dioxide (SiO_2), %	34.86	6.84
Aluminum Oxide ($Al2O_3$), %	32.05	1.39
Ferric Oxide ($Fe2O_3$), %	15.61	0.35
Calcium Oxide (CaO), %	0.94	46.30
Magnesium Oxide (MgO), %	0.71	1.91
Potassium Oxide (K_2O), %	0.00	0.41
Sodium Oxide (Na_2O), %	0.00	0.00
Sulfur Trioxide (SO_3), %	0.14	0.63
Titanium Oxide (TiO_2), %	1.94	0.00
Phosphorus Pentoxide (P_2O_5), %	0.14	0.00
Loss on Ignition (LOI), %	16.55	43.94

wheel load over a greater area of the weak subgrade so that the weak subgrade material will not be deformed, which will cause the road pavement to fail (Summers, 2000).

Figure 2 shows the variation of soaked CBR with different percentage of lime sludge. Considering the overall result, soaked CBR value increased from 12% to 26% when 10% lime sludge was added to expansive soil cured in 28 days. There was a 116.67 % increase in soaked CBR of the soil as compared to untreated soil. The reason for the increase in soaked CBR value of the soil could probably be due to the pozzolanic reaction between the lime present in lime sludge and with alumina and silica present in the expansive soil. The pozzolanic reaction is defined as one among many of the reactions that take place when lime is added to soil thus resulting to the production of new minerals such as calcium aluminate hydrates (Al-Mukhtar, Lasledj, & Alcover 2010). In addition, pozzolanic reactions are the reactions between lime, water, soils silica and alumina that form diverse cementing-type materials (The National Lime Association, 2004).

Substantial reductions in CBR were observed at all curing periods for 15% to 30% lime sludge content. It occurred due to carbonation reaction which took place as the presence of excess lime

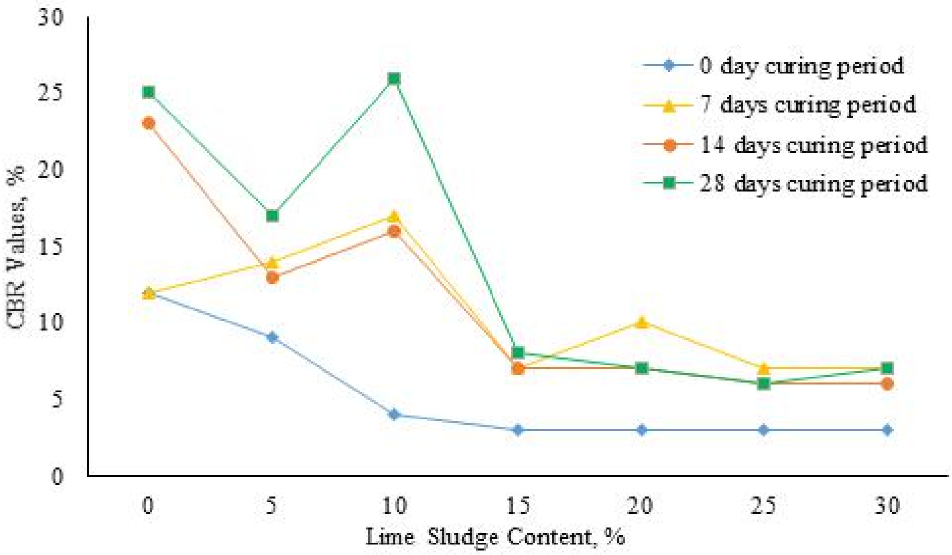

Figure 2. Effect of Sugar Mill Lime Sludge on the CBR

reacted with insufficient silica-alumina present in the expansive soil. Carbonation is a reaction of lime and carbon dioxide from the atmosphere to form relatively weak cementing agents, calcium and/or magnesium carbonate. It is an undesirable reaction and results in relatively insoluble carbonate that will not react with pozzolanic soils and render soils more plastic. Samantasinghar and Singh (2014) stated that when lime reacts with atmospheric carbon dioxide, carbonation may occur. This produces insoluble carbonate which has a negative influence on stabilization process, and it can be minimized by avoiding the exposure of lime to air and rainfall. Fang (2013) added that carbonation is an undesirable reaction that occurs when the lime added to soil does not react with soil but draws CO_2 from air or soil to form $CaCO_3$. This occurs when the soil does not contain an adequate amount of pozzolanic clay or because an excessive amount of lime has been added. $CaCO_3$ is a plastic material. It increases the plasticity of the soil and binds lime so that it cannot react with pozzolanic materials. Therefore, excessive lime addition to soil does not produce benefits. Little (1995) stated that unlike cement, where increases in dosage rate continue to strengthen the soil, lime has an optimal dosage rate for the maximum possible strength gain, which depends mainly on soil type and mineralogy.

Talukdar (2015) on his study on the stabilization of soil using the paper mill lime sludge observed that the CBR value increased with the addition of 15% lime mud in various types of soil which are dominantly silt. The percentage of increase depends on the type of soil. It implies that the optimum mixture to increase the CBR depends on the type of soil to be stabilized.

Effect of Curing Period on the CBR of the Treated Soil

Figure 3 shows the variation of CBR with respect to the curing period. The CBR of all mixtures increased during 28 days curing. As observed, untreated compacted soil with 28-day curing reached 25% CBR. It could be predicted in the graph that this value might hold constant or insubstantially increase if it would be allowed to cure for a longer period. For treated soil with 10% lime sludge, it reached 26% CBR, a very slight increase. However, its behavior on the graph showed that it might go on increasing or reaches higher value for extended curing. Continuous reduction in CBR as lime sludge content became higher at 0-day curing was observed apparently. In contrast, the mixtures with 5% to 10% had an increasing CBR value and was continually gaining its strength with respect to curing period. Lower CBR was observed from lower curing periods regardless of lime sludge content. It indicates that longer curing period will significantly increase the strength of soil.

It was observed that the CBR of 0% lime sludge decreased when 10% lime sludge was added at 0-day curing, increasing its value when cured for 7 days and went on increasing up to 28 days. This can be attributed to the thixotropic effect on soil. It temporarily lost its strength when disturbed (by mixing lime sludge to soil) and recovered when allowed to settle. Chan and Yong (2014) stated that when the soil is disturbed upon remolding, it may lose part or all of its strength. As time passes, the structural arrangement of the soil particles would be restored to a stable form, and the soil would regain hardness under constant volume and water content. They called the process as "thixotropic hardening." In addition, Jawad, Taha, Majeed, and Khan (2014) stated that as long as the lime content in the soil is enough, the process of pozzolanic reaction can continue for quite long durations - even decades. It is attributed to factors such as the temperature, quantity of calcium, pH, and the content of silica and alumina.

Little (1995) discussed that the long-term pozzolanic reactions begin as an increase in hydroxyl ions from the lime causes an increase in the pH of the soil water, which can begin to dissolve the silicate and aluminate sheets of the clay. As the silica and/or alumina are released,

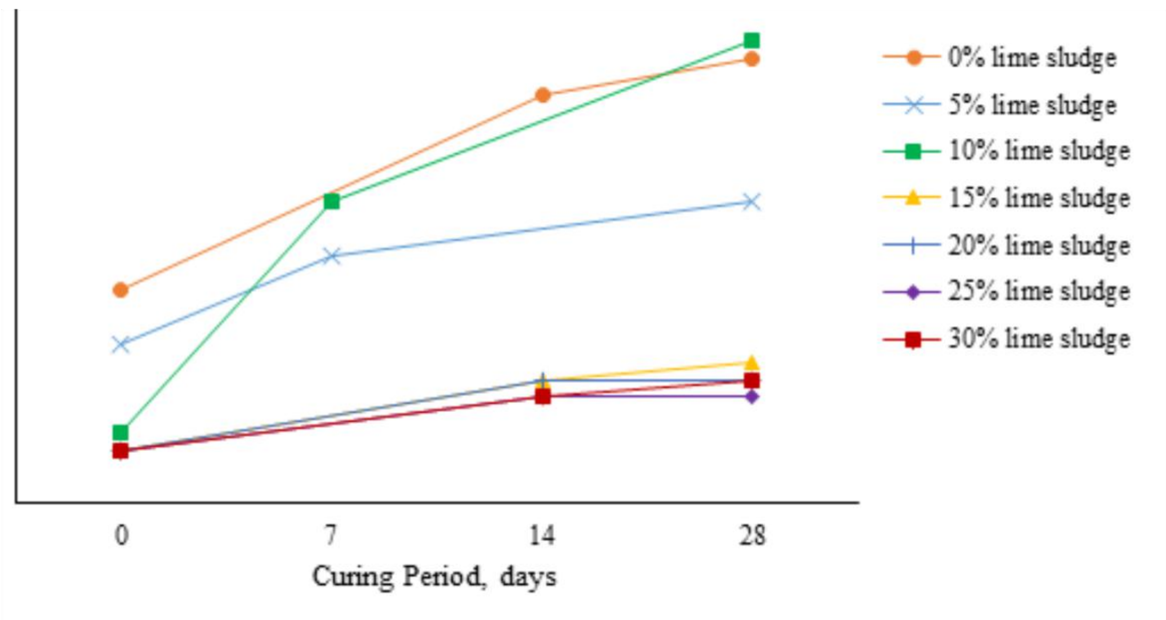

Figure 3. Effect of Curing Period on the CBR

they can combine with the calcium to form calcium silicate hydrates and/or calcium aluminate hydrates, which leads to cement in clay particles together.

Unconfined Compression Strength (UCS)

The unconfined compressive strength (UCS) is the maximum axial compressive stress that a right-cylindrical sample of material can withstand under unconfined conditions—the confining stress is zero. It is also known as the uniaxial compressive strength of material because the application of compressive stress is only along one axis—the longitudinal axis—of the sample.

Effect of Sugar Mill Lime Sludge on the UCS of the Treated Soil

Figure 4 shows the variation of UCS with different percentage of lime sludge. As the percentage of added lime sludge increased to 10% to each expansive soil, the UCS value also increased. It increased to a value from 67 kN/m² of uncured pure soil to 156 kN/m² when 10% lime sludge is added and considering the 28 days curing. There was a 102% increase in UCS of the soil compared to the neat soil. Further addition of 15% lime sludge significantly decreased the UCS of the soil. Increase in UCS is attributed to pozzolanic reaction while a decrease in strength at 5% lime sludge is due to the lack of lime to react to the soil while at 15% lime sludge is due to the carbonation where excessive lime sludge was added.

Effect of Curing Period on the UCS of the Treated Soil

Figure 5 shows the variation of UCS with respect to curing period. The UCS of all compacted soils increased at longer curing periods except for samples with 15% lime sludge content which noticeably decreased at 28 days curing pe riod. The largest UCS is experienced at 10% lime sludge content cured at 28 days. It implies

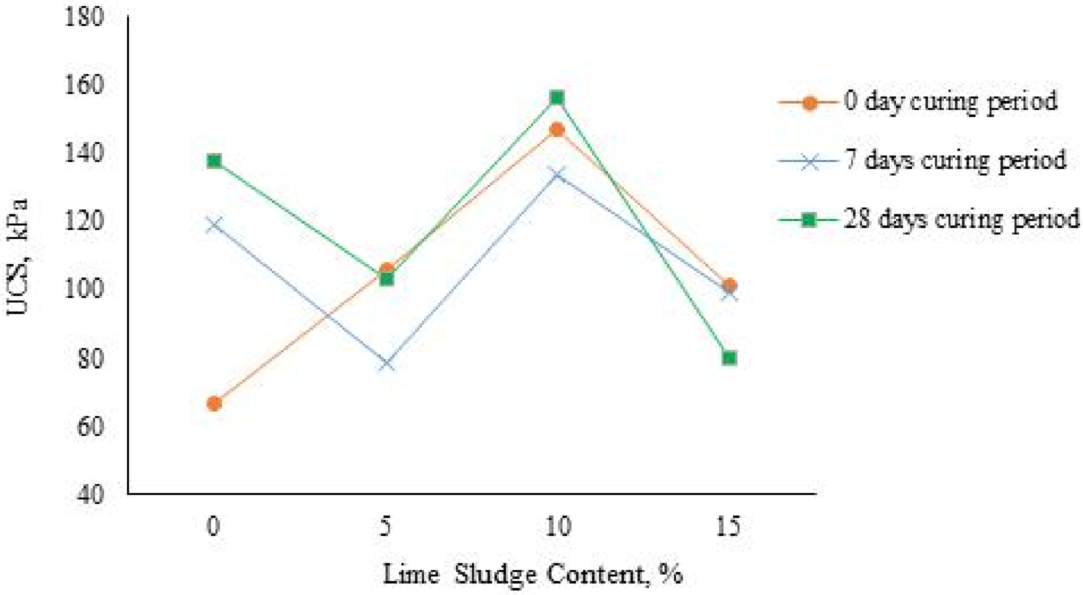

Figure 4. Effect of Sugar Mill Lime Sludge on the UCS

that the longer curing period will have a positive effect on the UCS of soil provided it is the optimum mixture.

Little (1995) and Aldaood et al. (2014) stated that lime-soil stabilization is associated with the long-term effect of the soil and are time and curing temperature dependent. This implies that the strength of the lime stabilized soil develops either positively or negatively gradually over a long period. Furthermore, Bhengu and Allopi (2016) stated that the long-term strength of lime soil stabilization is acieved when lime is added to reactive soil and allowed to generate strength for a longf period. The results of the study of Kavak and Baykal (2012) also supports the validity of the reaction on the long-term behavior of samples from their experimental evaluation. Their study investigated the changes in the micro-fabric of long-term cured lime-stabilized kaolinite clay soil. The unconfined compressive

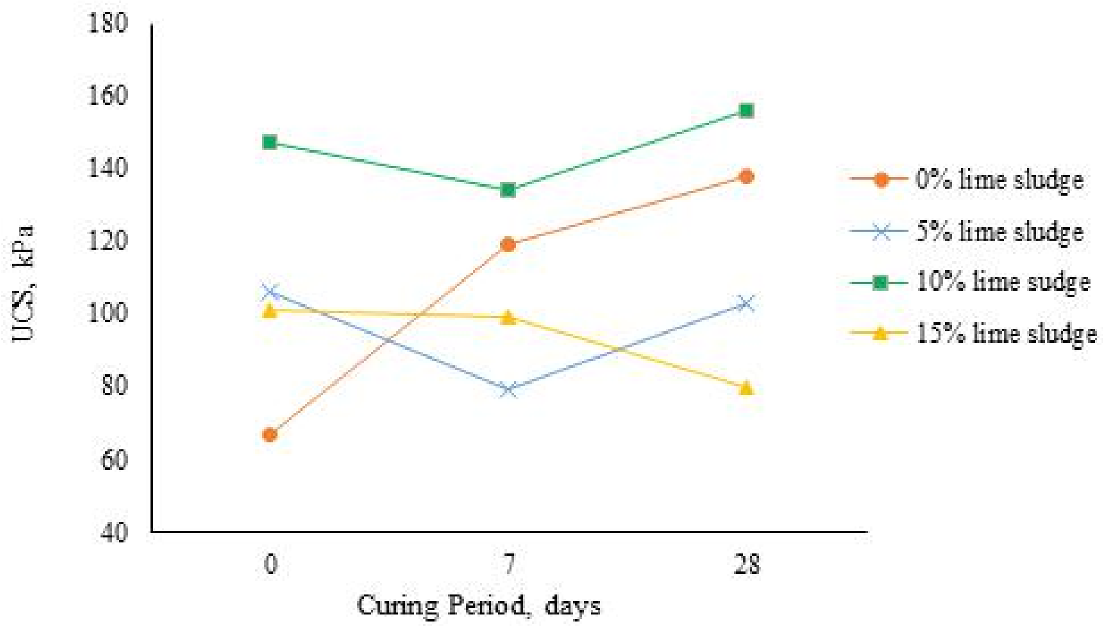

Figure 5. Effect of Curing Period on the UCS

strength of lime-stabilized kaolinite continuously increased when compared to that of the natural kaolinite clay samples.

Coban (2017) on his study observed that the highest increase in strength (48%) within the specimens prepared with lime sludge was observed in 90-day cured specimen prepared with 12% lime sludge. It implies that a longer curing period may increase the UCS of soil in this study.

CONCLUSION

In order to attain the maximum improvement in the engineering properties of an expansive soil treated with lime sludge, a proper selection of lime sludge content and curing period are crucial. Assessment of the effect of lime sludge content and curing period to the treated soils shows that maximum CBR is achieved at 10% lime sludge cured at 28 days. The same result on the assessment on the effect of these two factors to the UCS. A significant increase of CBR and UCS were expected at longer curing periods. On the other hand, treated soils with lime sludge con tents above and below 10% regardless of curing periods have indicated lower CBR and UCS, thus yielding inferior engineering properties. Results indicated that the optimum lime sludge content would be 10%. Therefore, the subgrade performance along the expansive clay area in Bukidnon can be improved by stabilization using the optimum mixture of 10% lime sludge and cured at a minimum of 28 days. Furthermore, treating the soil with locally available sugar mill lime sludge will have a significant impact on the proper utilization and disposal of this industrial waste.

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REFERENCES

Aldaood, A., Bouasker, M., & Mukhtar, M. A. (2014). Free swell potential of lime-treated gypseous soil. *Applied Clay Science, 102,* 93-103.

Al-Mukhtar, M., Lasledj, A., & Alcover, J. F. (2010). Behaviour and mineralogy changes in lime-treated expansive soil at 20°C. *Applied Clay Science, 50* (2). 191-198.

ASTM D1883. (2005). Standard test method for CBR (California Bearing Ratio) of laboratory-compacted soils. *USA:* American Society for Testing of Materials.

ASTM D 2166. (2005). *Standard test method for unconfined compressive strength of cohesive soil*. USA:ASTM International.

Bhengu, P., & Allopi, D. (2016). Review on the lime-soil stabilization as one of the successful technologies used in the improvement of road-soil-pavement layers strength. *Proceedings of the 35th Southern African Transport Conference (SATC 2016)*.

Bell, F.G B. (1989). Lime stabilization of clay soils. *Bulletin of Geology and the Environment, 39*(1), 67-74. DOI: 10.1007/BF02592537.

Chan, C-M., & Yong, H-Y. (2014). Comparing the thixotropic and lightly solidified hardening behavior of a Dredged Marine Clay. *Engineering, Technology & Applied Science Research.4* (5), 706-710.

Das, B. M. (2002). *Soil mechanics laboratory* manual, 6th Ed. United Kingdom: Oxford University Press.

Coban, H. S. (2017). *The use of lime sludge for soil stabilization.* Graduate Theses and Dissertations. Iowa State University. 15502. http://lib.dr.iastate.edu/etd/15502.

Dhakar, S., & S. K. Jain (2016). Stabilization of soil using flyash, slime & cement. International *Journal of Science and Research (IJSR). 5* (6), 527-529.

Fang, H-Y. (2013). F*oundation engineering handbook.* New York,Van Nostrand Reinhold

Hart, M.L. (1993). Characterization of lime sludge in engineering applications. *OhioLINK Journal Article. 13 (*1), 55-63.

Jawad, I. T., Taha, M. R., Majeed, Z. H. and Khan, T. A. (2014). Soil stabilization using lime: Advantages, disadvantages and proposing a potential alternative. *Research Journal of Applied Sciences, Engineering, and Technology, 8* (4), 510-520.

Kavak, A., & Baykal, G. (2012). Long-term behavior of lime-stabilized kaolinite clay. *Environ Earth Science.* 1944-1955.

Krithiga N., Pujitha, D., Palayam, T., & Revathy, A. (2017). Soil stabilization using lime and fly ash. *SSRG International Journal of Civil Engineering (ICRTCETM) Special Issue*, 510-518.

Kulkarni, T. A., Padalkar, P. A., & Joshi C. G. (2017). Stabilization of soil by using fly ash & lime. *3 Days International Conference on Recent Trends in Civil Engineering, Science and Management (ICCSM-17*). 32-38.

Little, D. N. (1995). *Handbook for stabilization of pavement subgrades and base course with lime*. Dubuque, Iowa, United States of America Lime Association of Texas.

Muntohar, A.S. (2006). The Swelling of Expansive Subgrade at Watespurworejo Roadway, Sta. 8+27. *Civil Engineering Dimension, 8* (2), 106–110.

National Lime Association. (2004). Lime-Treated Soil Construction Manual Lime Stabilization & Lime Modification. *National Lime Association Bulletin*, *326*, 1-43

O'Connell, M.J., & C.S Gourley. (1993). Expansive clay road embankments in arid areas: Moisture-suction conditions. *In Proceedings of the First International Symposium on Engineering Characteristics of Arid Soils. 6* (3), 254-260.

Samantasinghar, S,. & Singh S. P. (2014). *Geo-engineering properties of lime treated plastic soils*. Thesis. Department of Civil

Engineering, National Institute of Technology Rourkela, India

Shingloo, R. (2016). Design of flexible pavement by CBR method. *International Journal of Core Engineering & Management (IJCEM). 3* (2), 61.

Summers, C.J. (2000). Lime stabilization of soil subgrades. The Idiots' Guide to Highways Maintenance. Online. http://www.highwaysmaintenance.com/lime.htm.

Talukdar, D. K. (2015). A study of paper mill lime sludge for stabilization of village road sub-base. *International Journal of Emerging Technology and Advanced Engineering Website: www.ijetae.com (ISSN 2250-2459, ISO 9001:2008 Certified Journal). 5 (2)*, 389-393.

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