Shear Strength of Stabilized Kaolin Soil Using Liquid Polymer

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Abstract. The purpose of this research is to investigate the suitability of polymer in soil stabilization by examining its strength to withstand compressive strength. Throughout this research study, manufactured polymer was used as a chemical liquid soil stabilizer. The liquid polymer was diluted using a proposed dilution factor of 1 : 3 (1 part polymer: 3 parts distilled water) to preserve the workability of the polymer in kaolin mixture. A mold with a diameter of 50 mm and a height of 100 mm was prepared. Kaolin soil was mixed with different percentages of polymer from 10%, 15%, 20%, 25%, 30% and 35% of the mass of the kaolin clay sample. Kaolin mixtures were tested after a curing period of 3 days, 7 days, 14 days and 28 days respectively. The physical properties were determined by conducting a moisture content test and Atterberg limit test which comprise of liquid limit, plastic limit and shrinkage limit. Meanwhile, the mechanical properties of the soil shear strength were identified through an unconfined compressive strength (UCS) test. Stabilized kaolin soil showed the highest compressive strength value when it was mixed with 35% of polymer compared to other percentages that marked an increment in strength which are 45.72% (3 days), 67.57% (7 days), 81.73% (14 days) and 77.84% (28 days). Hence, the most effective percentage of liquid polymer which should be used to increase the strength of kaolin soil is 35%.

1.0 Introduction

As a rapidly developing country, Malaysia has shown immense progress in the construction sector. Soil serves as an engineering medium for the construction of civil structures [1]. However, limited stable soils are available worldwide due to the ever increasing human population and grain consumption [2]. Hence, optimizing the use of limited land must be done in order to cater to the increasing demand for development. Geotechnical engineers are responsible for coping with this predominant challenge by introducing innovative technologies for improving problematic soil [3][4].

Soil stabilization is the process of improving the physical and engineering properties of soil to achieve predetermined targets [5]. This can be done through mechanical, biological, physical, chemical and electrical methods. However, the use of acidic additives in soil may cause further pollution and dire consequences to the environment. Over the past decades, different methods have been introduced particularly by using chemical products as a soil stabilizer [6][7]. This is because the use of chemical products is convenient and cheaper as compared to other methods [8][9].

Stabilized soil will boost the shear strength of soil as well as its bearing capacity and permeability [10][11]. Furthermore, it is economically viable to increase the soil’s resistance against water ingress
in order to limit soil erosion and serious soil settlement. Nowadays, diverse techniques have been identified by geotechnical engineers to effectively treat problematic soil.

2.0 Materials and Methods

2.1 Kaolin Clay Soil

Kaolin clay is readily identifiable by its physical appearances which is normally white or grayish – white in color and classified as a very fine-grained powder compared to other clay soils. Kaolin clay is dominantly made up of hydrous aluminum silicate which is represented by a chemical composition of \( \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 \). It is a layer of silicate mineral consisting of one tetrahedral sheet of silica (\( \text{SiO}_4 \)) joined via oxygen atoms to one octahedral sheet of octahedral alumina [12].

The physical and chemical composition of kaolin clay soil are very dependent on its geological and geographical rock formation as well as its processing characteristics from its origin. Kaolin can be classified into two main types namely primary (residual) or secondary (sedimentary) kaolin[12]. The general formation of kaolin is initiated with in situ aluminosilicate rock alteration by undergoing weathering, hydrothermal and more rarely, volcanic processes. Kaolinite structure possesses a great advantage in many processes due to its high chemical stability and low coefficient of expansion [12][13].

2.2 Physical and Engineering Properties of Kaolin Soil

The notable physical appearances of kaolin clay soil are easily recognized compared to other minerals. In general, kaolin clay soil exists as a white, fine grained powder which may contribute to its lower abrasiveness and controllable particle size[14]. Kaolin used is a clay mineral with a liquid limit of 68.5 % and plastic limit of 38.9 % and other physical properties can be seen in Table 1.

| Table 1. Physical Properties of Kaolin |
|----------------------------------------|
| Properties                              | Values  |
| Moisture Content                        | 1.74 %  |
| Specific gravity, Gs                    | 2.31    |
| Liquid Limit, LL                        | 68.5 %  |
| Plastic Limit, PL                       | 38.9 %  |
| Plasticity Index, PI                    | 29.6    |
| Linear Shrinkage                        | 4.25    |

2.3 Liquid Polymer Chemical as a Soil Stabilizer

Liquid polymer obtained from the supplier, Dairen Chemical (M) SDN BHD, is used as a chemical agent to be used for soil stabilization. Initially, the kaolin clay soil sample is mixed with a dilution factor of 1 : 3 as seen in Figure 1 and then thoroughly mixed with different percentages of polymer from 10%, 15%, 20%, 25%, 30% and 35% of the total mass of kaolin soil used in the mixer as seen in Figure 2. The soil samples were tested after curing period of 3 days, 7 days, and 14 days. The stabilized kaolin clay soil was then tested through a number of tests at the Research Center for Soft Soils, UTHM. Previously, studies on the stabilization of kaolin soil have been conducted by other researchers [15][16].

This research mainly focuses on several methods to identify the shear strength of stabilized kaolin soil. In order to determine the physical properties of the investigated soil, the water content test and Atterberg limit test and and shrinkage limit were conducted. On the other hand, mechanical properties were obtained through an unconfined compressive strength (UCS) test in order to analyze the shear strength performance of stabilized kaolin soil [17].
3.0 Results and Discussion

The results were tabulated and analyzed to point out the physical and mechanical characteristics of the kaolin soil samples. Additionally, the unconfined compressive shear strength of kaolin soil was determined to investigate the ability of the soil samples to withstand the application of loads.

3.1 Unconfined Compressive Strength (UCS) Test

The Unconfined Compressive Strength (UCS) test was conducted to identify the maximum compressive strength of stabilized kaolin soil. Figure 3 shows a relationship graph between unconfined compressive strength and varying percentages of diluted DCC polymer correlated with the curing periods. It can be observed that the increasing percentage of the stabilizing agent will increase the value of compressive strength and supported by the past research[18][19]. Diluted polymer is added to the soil when necessary to sufficiently coat the entire surface of aggregates.

![Figure 3. Compressive strength against varying percentages of DCC polymer.](image)

Based on the Figure 4, the curing period did not portray a constant increase in terms of compressive strength. However, the curing periods used throughout this research namely 3 days, 7 days, 14 days and 28 days offer a different pattern of strength increment dependent on the percentages of polymer used.
Figure 4. Relationship between unconfined compressive strength against curing period corresponding to the varying percentages of polymer.

Based on the 3-day curing period, the percentage of 15%, 20%, 25% and 30% of polymer have maintained their strength whereas 35% of polymer has shown dramatic increment in terms of compressive strength as compared to the strength of pure kaolin soil samples. However, for 7, 14 and 28 days curing have shown steady increment in different percentage of polymer as seen in Figure 5. Hence, the addition of polymer to a certain percentage is capable of increasing the strength of stabilized kaolin soil as proven by previous study[20].

Figure 5. Percentage increment against the percentage of polymer

As shown in Figure 6, it can be observed that a longer curing period is effective for strengthening and stabilizing the treated kaolin soil. Polymers can act as a stabilizing mechanism dependent on the evaporation of water which generates a continuous matrix coated around the soil aggregates [21]. The polymer deposited on the surface will protect the soil structure by bridging the soil structure which in turn enhances the strength of soil [22].
4. Conclusion
The aim of this research is to identify the effects of different percentages of polymer (10%, 15%, 20%, 25%, 30% and 35%) on manufactured kaolin clay soil by studying the values of unconfined compressive strength within certain curing periods (3, 7, 14 and 28 days). Based on the results obtained, it can be concluded that the polymer of dilution factor of 1:3 can be used for soil stabilisation and has potential to be used in various civil engineering applications. Additional laboratory studies are required for continuous research on the behavior of polymers and to determine the optimum polymer content and stabilization process for various applications. Besides that, further investigation need to be done via field research studies. It is recommended to test the efficiency of polymers with other emulsion mixtures or materials to examine their potential to provide added strength for problematic soils such peat soil and residual soil [23]. Through this study, the series of data that are generated may be used as a reference to distinguish the shear strength which can be achieved by other types of manufactured chemical soil stabilizers [24].

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References
[1] B. State, H. O. Nwankwoala, A. N. Amadi, F. A. Ushie, T. Warmate, and C. J. Eze, “Determination of Subsurface Geotechnical Properties for Foundation Design and Construction in Akenfa,” vol. 2, no. 4, pp. 130–135, 2014.
[2] D. Pimentel, M. Whitecraft, Z. R. Scott, L. Zhao, P. Satkiewicz, T. J. Scott, J. Phillips, D. Szimak, G. Singh, D. O. Gonzalez, and T. L. Moe, “Will Limited Land , Water , and Energy Control Human Population Numbers in the Future,” no. Prb 2008, 2010.
[3] J. K. Mitchell, J. Kopmann, J. K. Mitchell, and J. Kopmann, “Virginia Polytechnic Institute And State University The Charles E. Via , Jr. Department of Civil Engineering Center For The Future of Geotechnical Engineering,” no. January, 2013.
[4] Z A M Hazreek, M Aziman, A T S Azhar, W D Chitral, A Fauziah and S Rosli (2015) The Behaviour of Laboratory Soil Electrical Resistivity Value under Basic Soil Properties Influences, IOP Conference Series: Earth and Environmental Science, Vol 23, pp. 1-7.
[5] F. Ali, “Stabilization of Residual Soils Using Liquid Chemical,” pp. 115–126, 2012.
[6] M. Parmar and L. S. Thakur, “Review article Heavy Metal Cu , Ni And Zn: Toxicity , Health Hazards And Their Removal Techniques By Low Cost Adsorbents : A Short Overview . pp.
143–157, 2013.

[7] Tajudin S A A, Marto A, Azmi M A M, Madun A & Abidin M H Z, 2015 Utilization of sugarcane Bagasse ash for stabilization/solidification of lead-contaminated soils, Jurnal Teknologi 77(11) 119-125

[8] Ling J H, Sabarudin M, Saiful A A T, Syazie N A M, Ismail B, Mohd I M M, Adnan Z & Ali A W M, 2016 Construction of Infrastructure on Peat: Case Studies and Lessons Learned, MATEC Web of Conferences, 47 03014

[9] Tajudin S A A, Azmi M A M & Nabila A T A, 2016 Stabilization/Solidification Remediation Method for Contaminated Soil: A Review, IOP Conference Series: Materials Science and Engineering 136 1-6.

[10] A. J. Bloodworth, “Industrial Minerals Laboratory Manual Kaolin,” 1993.

[11] Z A M Hazreek, S Rosli, W D Chitral, A Fauziah, A T S Azhar, M Aziman1 and B Ismail, (2015) Soil Identification using Field Electrical Resistivity Method, Journal of Physics: Conference Series, Vol 622 pp 1-7

[12] J. C. Miranda-trevino and C. A. Coles, “Kaolinite properties, structure and influence of metal retention on pH,” vol. 23, pp. 133–139, 2003.

[13] Yusof, M.F., Setapa, A.S., Tajudin, S.A.A., Madun, A., Abidin, M.H.Z., Marto, A. (2015) The Soil-Water Characteristic Curve of Unsaturated Tropical Residual Soil, IOP Conference Series: Materials Science and Engineering Vol 136.

[14] Juliana, “Particularity of plasticity characteristics of fine glacial materials (North Chicago area),” no. 1, 2011.

[15] A. Eisazadeh, K. A. Kassim, and H. Nur, “Stabilization of tropical kaolin soil with phosphoric acid and lime,” pp. 931–942, 2012.

[16] Azhar, A.T.S., Azim, M.A.M., Aziman, M., Nabila, A.T.A., (2015) Leachability of Arsenic (As) Contaminated Landfill Soil Stabilised by Cement and Bagasse Ash, IOP Conference Series: Materials Science and Engineering, 160 (1)

[17] S. Sapkota, M. Dhingra, and S. Jayalekshmi, “Review On Soil Stabilization Techniques,” vol. 3, no. 3, pp. 63–78, 2014.

[18] I.Syafiq, “Strength Of Kaolin Stabilized With Various Percentage Of,” no. June, 2015.

[19] Tajudin S A A, Azmi M A M, Shahidan S, Abidin M H Z & Madun A, 2016 Relationship of physical parameters in Pb-contaminated by stabilization/solidification method, MATEC Web of Conferences 47 03015.

[20] A. Muhmed, “Effect of Lime Stabilisation on the Strength and Microstructure of Clay,” vol. 6, no. 3, pp. 87–94, 2013.

[21] R. K. Layek and A. K. Nandi, “Feature article A review on synthesis and properties of polymer functionalized graphene,” vol. 54, no. 19, pp. 5087–5103, 2013.

[22] C. J. Bronick and R. Lal, “Soil structure and management: a review,” vol. 124, pp. 3–22, 2005.

[23] Ali A W M, Sabarudin M, Mohd I M M, Saiful A A T, Ismail B, Adnan Z, Azrul Z K & Ling J H, 2016 Construction of Buildings on Peat: Case Studies and Lessons Learned, MATEC Web of Conferences 47 03013

[24] Pakir, F., Marto, A., Yunus, N.Z.M., Tajudin, S.A.A., Tan, C.S., (2015) Effect of sodium silicate as liquid based stabilizer on shear strength of marine clay Jurnal Teknologi, 76 (2), pp. 45-50.