Jurnal
Teknologi

Full Paper

STRENGTH CHARACTERISTIC OF BROWN KAOLIN TREATED WITH LIQUID POLYMER ADDITIVES

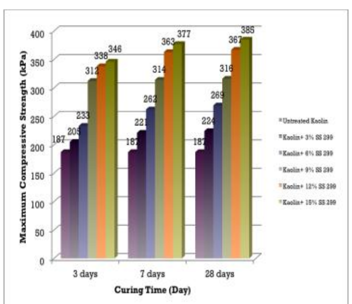
Aminaton Marto[a], Sanjay Boss[a]*, Ahmad Mahir Makhtar[b], Nima Latifi[a]

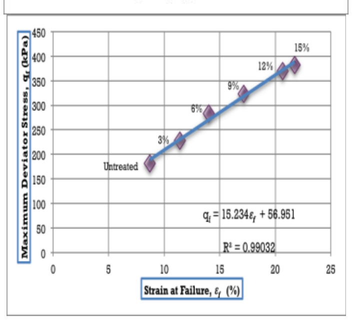
[a]Soft Soil Eng. Research Group, Group, Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Industrialised Construction System Research Group, Innovative Engineering Research Alliance,
Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

Article history
Received
6 July 2015
Received in revised form
26 July 2015
Accepted
30 July 2015

*Corresponding author:
sanjay_boss@hotmail.com

Graphical abstract





Abstract

Kaolin deposits are considered to have poor engineering characteristics, exhibiting expansive properties, high plasticity, poor workability, and low shear strength. This may cause severe damage to civil engineering structures and facilities. Hence, these soils must be treated prior to construction operations, so that desired properties can be achieved. SS 299 is a liquid polymer stabilizers used as a compaction aid or a stabilizer for soil improvement. Yet, it is not used as a common approach when comes to soil stabilization due to its uncertainties in strength improvement when mixed with soils. As a result, laboratory testing programs were conducted to study the strength development of brown kaolin when treated with the liquid polymer with 3 %, 6 %, 9 %, 12 % and 15 % of soil's dry mass. The result indicated that the increase in the percentage of SS 299, increases the unconfined compression strength. The maximum value of the unconfined compressive strength of 385 kPa was observed at 15 % SS 299 content, cured at 28 days, which was twice the strength of the untreated brown kaolin. The increment of strength was really steep for the first 7 days but the rate decreased thereafter. The optimum content of liquid polymer SS 299 was found as 12 %.

Keywords: Stabilization; water based polymer; brown kaolin; curing time

Abstrak

Endapan kaolin dianggap mempunyai ciri-ciri kejuruteraan yang lemah, mempamerkan sifat mengembang, keplastikan yang tinggi, kebolehkerjaan yang rendah, dan kekuatan ricih yang rendah. Ini boleh menyebabkan kerosakan teruk kepada struktur kejuruteraan awam dan kemudahan. Oleh itu, tanah ini perlu dirawat sebelum operasi pembinaan, sehingga sifat yang dikehendaki dapat dicapai. SS 299 adalah penstabil polimer cecair yang digunakan untuk membantu pemadatan atau sebagai penstabil untuk pembaikan tanah. Namun, ia tidak digunakan sebagai pendekatan yang umum bagi penstabilan tanah berikutan ketidaktentuan dalam peningkatan kekuatan apabila dicampur dengan tanah. Oleh itu, program ujian makmal telah dijalankan untuk mengkaji peningkatan kekuatan kaolin coklat apabila dirawat dengan polimer cecair dengan kandungan 3 %, 6 %, 9 %, 12 % dan 15 % daripada jisim tanah kering. Hasil menunjukkan bahawa peningkatan dalam peratusan SS 299, meningkatkan kekuatan mampatan tidak terkurung. Nilai maksimum kekuatan mampatan tak terkurung sebanyak 385 kPa diperolehi pada 15 % kandungan SS 299, pada awetan 28 hari, iaitu dua kali kekuatan kaolin coklat yang tidak dirawat. Peningkatan kekuatan adalah sangat tinggi untuk 7 hari pertama, tetapi pada kadar yang menurun selepas itu. Kandungan optimum polimer cecair SS 299 adalah didapati sebagai 12 %.

Kata kunci: Penstabilan; polimer berasaskan air; kaolin coklat; masa awetan

1.0 INTRODUCTION

The improvement of the soil's physical and engineering properties to a predetermined value is known as the soil improvement. According to Hejazi *et al.* [1] there are many ways to improve soils physical and engineering properties, e.g. mechanical, physical, chemical, biological and lastly electrical. For many decades, the use of traditional soil stabilizers, e.g. lime, fly ash, cement and bituminous materials, are the first choice to improve the engineering properties of a weak soil. These stabilizers are considered to have successful usage for pavement base and highway subgrade. Nevertheless, the effect of these stabilizers to the environment is a problem that needed to be acknowledged. Besides that, these bulk stabilizers products are highly expensive and also hard to achieve the quality control. Furthermore, the presence of the sulphate in the soil and the calcium-based stabilizer will stimulate a reaction between them and cause excessive expansion to the soil while the stabilization process [2].

Currently, the research done by Marto *et al.* [3] presented the use of GKS soil stabilizer (SS 299) on the laterite soil to improve its strength. The results showed a gradual increase in the soil strength with the increase concentration of SS 299 to the soil specimens. The different curing time also influences the strength characteristic of the treated soil. The longer the curing time, the higher the developed strength. The unconfined compression strength of an untreated laterite soil was 270 kPa. The strength of the soil with the 12 % mixture of the stabilizer showed the maximum strength developed, which was 605 kPa after the curing time of 28 days.

Whereas, the results from Yunus *et al.* [4] for the laterite mixed with liquid polymer (SS 299), the strength developed was at a very slow rate, whereby the after 3 days and 7 days curing but visible changes in strength only after the 28 days curing. The researcher used different percentages of SS 299; 2 %, 8 %, and 16 %. The maximum strength of the treated soil reached a high of 650 kPa at the curing time of 28 days.

Naeini *et al*. [5] conducted experiments to evaluate the outcome of various plasticity index and the waterborne polymer on the unconfined compressive strength of the clayey soils. The results obtained showed that the unconfined compressive increases as the plasticity index decreases. Also, the waterborne polymer did improve the strength of the clayey soil for different amount of polymer i.e. 2 %, 3 %, 4 % and 5 %. The unconfined compressive strength significantly increases with the curing time. The strength developed in higher rate in the first 8 days but become almost constant up to 14 days.

Studies by Santoni et al. [6] and Zandieh and Yasrobi [7] have shown that the polymer emulsions do provide significant strength gain and added strength under wet conditions. The unconfined compressive strengths were used to measure the strength gained. The researchers demonstrated that the polymer mixed with soil improves the soil properties with the increment of the curing time. By 'breaking' of the emulsion and the subsequent water loss by evaporation, the curing of the polymer emulsion occurred. The breaking of the emulsion occurs when the individual emulsion droplets suspended in the water phase coalesce. This occurs as the emulsion particles wet the surface of the soil particle, and the polymer would be deposited on the surface. The concentration of the polymer introduced into the soil mixture and the degree of the mixing between the soil and the polymer determine the amount of polymer deposited on the surface of the soil particles

Recently, there are varieties of non-traditional soil stabilizer that are commercially accessible in the market. According to the Tingle et al. [8] non-traditional stabilizers are acids, enzymes, electrolytes, resins, sulfonated oils, mineral pitches and polymers. Most of these products are usually advertised as either a compaction aid or a stabilizer. Among these non-traditional stabilizers mentioned, liquid polymer (SS 299) have been made more aware by commercial suppliers and distributors such as the GKS Soil Stabilizer Sdn. Bhd.

Liquid Polymer SS 299 is eco-friendly, lead free, non-toxic and user-friendly water soluble polymers. They act to break or diminish the water membrane surrounding the soil particles. Upon compaction, it will enhance and improve the condition of the targeted soil with significant load resistance. SS 299 acts as a surface agent or surfactant where it transforms the hydrophilic nature of clayey material into hydrophobic nature through an ionization process and chemical reaction when it dissolves in water. SS 299 induces a negative charge on the surface of the clay soil particles. It reduces the amount of pore water capillary and discharges the water content in the soil [9].

Usually, liquid polymer stabilizer is distributed as concentrated or diluted with water at the site and then sprayed on subgrade soil. According to the suppliers and distributors potential advantages are higher compacted dry density, shear strength as well as waterproofing effect of this product could be obtained for the treated soils [8]. The polymer stabilizer coats soil particles, and physical bonds are formed when the emulsion water evaporates, leaving a soil–polymer matrix. As with asphalt emulsions, the emulsifying agent can also serve as a surfactant, improving penetration for topical applications and particle coating for admix conditions. Because the primary stabilization mechanism is physical bonding, the improvement in strength depends on the ability to coat the soil particles adequately and on the physical properties of the polymer [9].

Despite the potential advantage performances claimed by liquid polymer stabilizer providers, most agencies and engineers are resistant to accept the use of these products. SS299 can cause a certain lack of confidence to the engineers to use it in actual construction because the liquid polymer's chemical composition is often not listed full, which makes it difficult to understand the mechanism of stabilization. They also failed to demonstrate the benefits of their products with data from standard laboratory testing methods i.e. field performance data from treated and untreated sections are poorly documented and lack of long term results. SS 299 suppliers cannot specify application ratios according soil types therefore standard laboratory testing protocol concerning application ratios needs to be set up.

In this study, the strength characteristic of brown kaolin stabilized with liquid polymer additive (SS 299) was studied. The strength development of brown kaolin treated with liquid polymer additive at different percentage of additive contents (3 %, 6 %, 9 %, 12 % and 15 %) and different curing time (3 days, 7 days and 28 days) were determined.

2.0 MATERIAL AND TESTING PROGRAMME

A bag of 20 kg of brown kaolin soil was purchased from Tapah, which is located in the state of Perak in Peninsular Malaysia. Firstly, the brown kaolin was oven dried at a temperature of approximately 100 ± 5°C for 24 hours to ensure that there is no moisture in the sample [10]. Then, the clay sample was kept in an airtight container to ensure the dryness of the soil. Figure 1 presents the airtight container that was used to keep the oven dried kaolin samples. The liquid polymer additives (SS 299), used in this study had been prepared by the manufacturer GKS Soil Stabilizer Sdn. Bhd., which is located in Johor.

Figure 1 Oven dried soil, kept in the airtight container

The laboratory tests were conducted in accordance with the British Standard [10]. To ensure a viable result from the testing, replication of the tests were done. The physical and engineering properties of the brown kaolin are presented in Table 1. Soil is categorized as silt with high plasticity.

Table 1 Properties of the brown kaolin

PROPERTY	VALUES
Particle Density	2.66 Mg/m³
Grain Size (USCS)	
Sand (0.075-2.0 mm)	17 %
Silt (2-75 μm)	52 %
Clay (< 2μm)	31 %
Atterberg Limit	
Liquid Limit	52 %
Plastic Limit	32 %
Plasticity Index	20 %
Standard Proctor Compaction Parameter	
Maximum Dry Density	1.53 Mg/m³
Optimum Moisture Content	24 %
Unconfined Compressive Strength	187 kPa
Soil Classification, (BSCS)	MH

3.0 SPECIMEN PREPARATION

Results obtained from the compaction tests play an important role in the preparation of treated specimen. All the treated specimens were prepared referring to its compaction at maximum dry densities (MDD) and optimum moisture contents (OMC). The required dry mass of soil samples had been calculated with the reference of the mould volume and the MDD [11]. Predetermined quantities of SS 299 were then measured based on the dry mass of soil sample and mixed until homogenous. The soil specimen was then mixed with water content corresponding to the OMC.

Mixing process was carried within a reasonable time (approximately five to ten minutes) to ensure that the polymer emulsions were not exposed to the air for too long [3]. The percentages of the SS 299 added to the brown kaolin soil were 3 %, 6 %, 9 %, 12 % and 15 %. The specimens were mixed thoroughly and compacted into the 38 mm x 76 mm cylindrical mould, which requires the usage of hydraulic jack. The inner surface of the brass mould was layered with a thin, transparent sheet to minimize friction. After that, the specimens were extruded from the mould and wrapped with a cling film to preserve the water content and prevent from the carbon dioxide (CO_2) exposure. The samples were then stored for curing time in a controlled temperature room (27 ± 2°C) until required for testing at each of the curing periods of 3, 7, and 28 days [12].

4.0 UNCONFINED COMPRESSIVE STRENGTH TEST

After reaching the specified curing time, samples were taken out from the airtight container. Next, the dimensions and weight of the samples were measured. The unconfined compressive strength test was conducted in accordance to the BS 1377: Part 2: 1990: 4.1 [2]. A specimen was carefully placed in the compression device. The test was carried out at the loading rate of 1.52 mm/min until the sample failed [13].

During the test, the applied load and the changes in the axial deformation were recorded automatically by the data acquisition unit (ADU) with failure being defined as the peak axial stress. At the end of each test, the failed brown kaolin specimen was oven dried and weighed to determine its moisture content. The tests were repeated for the other samples as mentioned above. For the purpose of getting an accurate result, three samples for each soil mix design were prepared [13]. The UCS was determined by taking the average of three test results, which gave close results to each other.

5.0 RESULTS AND DISCUSSION

The results and discussion on the unconfined compressive strength of both untreated and treated brown kaolin with 3 %, 6 %, 9 %, 12 % and 15 % of SS 299 were focused in this part.

5.1 Unconfined Compressive Strength

The effectiveness of the liquid polymer additive can be investigated by using the UCS test. The tests were done on different percentage of chemical content and different curing time. The compressive strength of untreated brown kaolin was 187 kPa and with increase of chemical additives, there was a significant increase in the compressive strength of the soil.

The value of unconfined compressive strength of samples with different SS 299 concentration and curing time was presented in Figure 2. As shown, an increased in the concentration of the liquid additives and the increase in the curing time induced a significant increased in the unconfined compressive strength of the brown kaolin. The maximum value of the unconfined compressive strength was 385 kPa, which can be observed at 15 % SS 299 concentration at 28 days of curing period that was two times more than the strength of untreated brown kaolin.

It is also can be observed that the increment of strength was really steep for the first 7 days then it just increased with a lower rate. Last but not least, the increment of the strength with respect to the untreated brown kaolin in percentage for each concentration of SS 299 at 28 days were 20 % (3 % of SS 299), 44 % (6 % of SS 299), 69 % (9 % of SS 299), 96 % (12 % of SS 299) and 106 % (15 % of SS 299). Therefore, the optimum concentration of liquid polymer SS 299 was taken as 12 %.

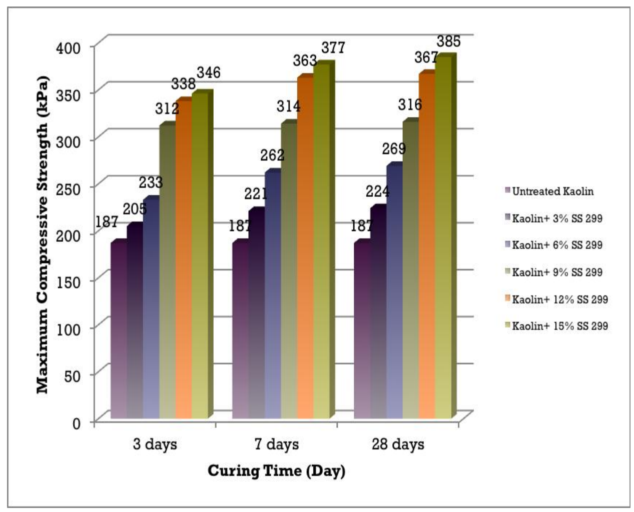


Figure 2 Unconfined compressive strength with different curing periods

5.2 Effect of Polymer Content on Stress-Strain Behaviour

By observing the stress-strain plots of the tests in Figure 3, one can conclude that, the deviator stress and the strain increased as the percentage of additive increased, indicating that, the concentration of the liquid polymer additive increased the strain respectively. This means with an increase in the polymer content, the treated soil shows a greater strength at an increasing strain. In other word, increasing polymer content leads to a constant value in the stiffness of brown kaolin. Besides that, the gradient of the stress-strain curves are relatively similar for the untreated and treated brown kaolin, which also indicate that the stiffness of the soil constant in value.

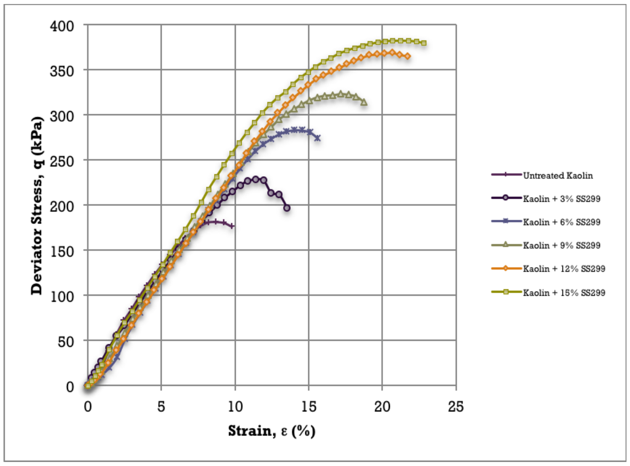


Figure 3 Deviator stress against strain at 28 days curing

5.3 Relationship Between The Maximum Deviator Stress And Strain At Failure

By plotting the maximum deviator stress against the maximum strain as shown in Figure 4, a linear relationship can be seen. This linear equation was obtained by performing the linear regression from the data as follows:

$$q_f = 15.234\, \varepsilon_f + 56.951 \qquad (1)$$

in which, q_f = maximum deviator stress (kPa)
ε_f = strain at failure

The coefficient of determination, R^2 was 0.99, which indicated that the equation is very reliable. Yet there are a few limitations to this equation: The equation can be only used to determine the strength and strain of brown kaolin cured for 28 day and the range of the liquid polymer additive was between 0% to15 % only. Besides that, the gradient of the stress-strain curves are relatively similar for the untreated and treated brown kaolin, which also indicate that the stiffness of the soil is constant in value.

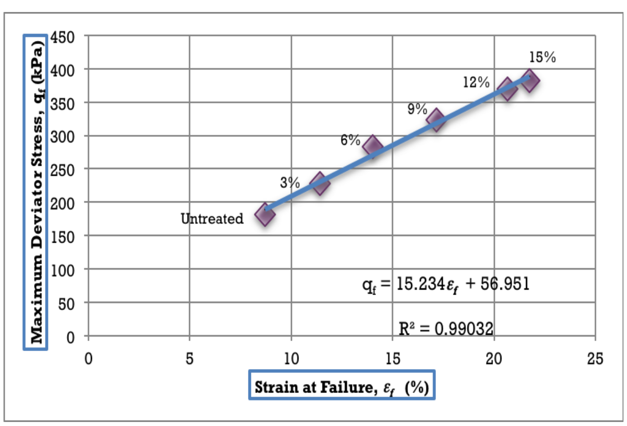


Figure 4 Maximum deviator stress against strain at failure of untreated and treated brown kaolin at 28 days curing

6.0 CONCLUSION

The unconfined compressive strength of compacted untreated brown kaolin was 187 kPa. The result indicated that the increased in the percentage of SS 299, increased the unconfined compression strength. The maximum value of the unconfined compressive strength of 385 kPa was observed at 15 % SS 299 content, cured at 28 days, which was twice the strength of the untreated brown kaolin. The increment of strength was really steep for the first 7 days but the rate decreased thereafter. The optimum content of liquid polymer SS 299 was found as 12 %.

Acknowledgement

The authors are grateful to the technical staff of the Geotechnics Laboratory and Mechanical Laboratory of Universiti Teknologi Malaysia for their assistance during experimental works. The authors would also like to acknowledge the assistance rendered by all members of the Soft Soil Research Group. Not to forget to the GKS Sdn. Bhd. for providing the liquid polymer additive used in this study.

References

[1] Hejazi, S. M., Sheikhzadeh, M., Abtahi, S. M. and Zadhoush, A. 2012. A Simple Review of Soil Reinforcement by Using Natural and Synthetic Fibers. *Construction and Building Materials*.

[2] Saeed, K. A., Kassim, K. A. and Nur, H. 2014. Physicochemical Characterization of Cement Treated Kaolin Clay. *Journal of the Croatian Association of Civil Engineers*. 66: 513–521.

[3] Marto, A., Latifi, N. and Sohaei, H. 2013. Stabilization of Laterite Soil using GKS Soil Stabilizer. *Electronic Journal of Geotechnical Engineering*. *18 C*: 521–532.

[4] Yunus, N. Z. M., Wei, N. T., Yung, Y. C., Marto, A., Pakir, F., Hezmi, M. A. and Saari, R. 2014. Effectiveness of Canlite and Probase Stabilized Laterite Soil Akademia Baru. *Journal of Advanced Research Design*. *5*(1): 17–30.

[5] Naeini, S. A., Naderinia, B. and Izadi, E., 2012. Unconfined Compressive Strength of Clayey Soils Stabilized with Waterborne Polymer. *KSCE Journal of Civil Engineering*. 16(6): 943–949.

[6] Santoni R. L., Tingle J. S. and Webster S. L. 2003. Stabilization of Silty Sand with Non-Traditional Additives, *Transportation Research Record 1787*, TRB, National Research Council, Washington. DC. 33–41

[7] Zandieh, A. R. and Yasrobi, S. S. 2010. Study of Factors Affecting the Compressive Strength of Sandy Soil Stabilized with Polymer. *Geotechnical and Geological Engineering*. 28(2): 139–145.

[8] Tingle, J., Newman, J., Larson, S., Weiss, C. and Rushing, J. 2007. Stabilization Mechanisms of Nontraditional Additives. *Transportation Research Record*. 1989(1): 59–67.

[9] Wei, N. T. 2014. *Comparison between Canlite Stabilized Laterite and Probase Stabilized Laterite*. Universiti Teknologi Malaysia.

[10] British Standard 1377-1. 1990. Methods of Test for Soils for Civil Engineering Purposes. General Requirements and Sample Preparation. BSI Group.

[11] British Standards, I. 1990. BS 1377-4:1990 Methods Of Test For Soils For Civil Engineering Purposes— Part 4: Compaction-related tests. *British Standard*. 3.

[12] Latifi, N., Eisazadeh, A. and Marto, A. 2014. Strength Behavior and Microstructural Characteristics of Tropical Laterite Soil Treated with Sodium Silicate-based Liquid Stabilizer. *Environmental Earth Sciences. 72*(1): 91–98.

[13] Marto, A., Latifi, N. and Eisazadeh, A. 2014. Effect of Non-Traditional Additives on Engineering and Microstructural Characteristics of Laterite Soil. *Arabian Journal for Science and Engineering*. 6949–6958.