MICACEOUS SOIL STRENGTH AND PERMEABILITY IMPROVEMENT INDUCED BY MICROBACTERIA FROM VEGETABLE WASTE

R.C Omar 1,a, R. Roslan 2,b, I.N.Z Baharuddin 3,c and M.I.M Hanafiah 4,d

1,2,3,4 & 5 Centre for Forensic Engineering, College of Engineering, UNITEN, Selangor, Malaysia.

E-mail:  a rohayu@uniten.edu.my,  b rasyikin@uniten.edu.my,  c intan@uniten.edu.my,  d izzatvalo@yahoo.com

Abstract. Green technology method using vegetable waste are introduced in this paper for improvement of phyllite residual soil from UNITEN, Campus. Residual soil from phyllite are known as micaceous soils and it give problem in managing the stability of the slope especially in wet and extensively dry seasons. Micaceous soil are collected using tube sampler technique and mixed with liquid contain microorganism from fermented vegetable waste name as vege-grout to form remolded sample. The remolded sample are classify as 15.0%, 17.5%, 20.00% and 22.5% based on different incremental percentages of vege-grout. The curing time for the sample are 7, 14, 21, 28, and 35 days before the tests were conducted. Observation of the effect of treatment shows 20.0% of liquid contain Bacillus pasteurii and Bacillus Subtilis with 21 days curing time is the optimum value in strengthening the soil and improve the permeability.

Introduction

Residual soil from phyllite are known as micaceous soils. The nature, size and proportion of mica in a soil depends on the type of parent rocks and the degree of weathering, topography of the site, annual rainfall and drainage characteristic. Normally, micaceous soil derived from the physico-chemical weathering of chloride-muscovite or biotite-muscovite bearing rock such as phyllite, schist and gneiss from clastic sedimentary rocks. Due to weathering, these chloride-muscovite or biotite-muscovite bearing rocks contain mica bands and sheets which progressively break down into smaller sizes [1] and [2]. When a soil contains an appreciable amount of mica it has the tendency to be highly expansive and unstable when saturated. These condition occur because of the mechanical properties especially the strength decrease, easily to over saturate and density start to reduced.

Improvement method for stabilization of soil is desirable such using constructive approaches like compaction, adding nails or sheets in a slope or mixing soil with lime or cement (Karol 2003). Ecological or combined approaches normally are used to prevent erosion like planting trees, grasses and shrubs or stimulate mussel beds [3], [4], [5], [6] and [7]. In situ strengthening techniques like cement or chemical grouting are used, when stabilization of a soil mass is required because surficial techniques such as deep mixing are insufficient [8]. However, chemical grouting techniques are often costly and require many injection wells for treating large volumes, due to the high viscosity or short hardening time of the injected grouts [9]. In addition, these methods significantly reduce the permeability of the strengthened soil, which hinders groundwater flow and limits long distance injection, making large scale treatment unfeasible [9].

Toward sustainable development, new technique for soil stabilization using potential biological techniques for ground reinforcement are introduced known as bio-grouting [10], [11] and [12]. According to [12] and [13], bio-grout that mixed with suitable substrates, the micro-organisms from bio-grout can catalyse chemical reactions in the subsurface resulting in precipitation (or dissolution) of inorganic minerals, which change the mechanical soil properties of treated soil. The micro-organisms introduce by [12], [14] and [15] are collected by urea hydrolysis and these micro-organisms can induced calcium carbonate precipitation (MICP) from sand to be used as bio-grout for ground reinforcement method.
The current understanding shows the micro-organisms induced calcium carbonate precipitation (MICP) from urea hydrolysis can treated sands but another alternative to produce micro-organism induced calcium carbonate precipitation (MICP) from others waste material and for fine grain soil such as silt or clay are less discuss. These paper aims to introduce vegetable waste as sources of producing bacteria for treatment of micaceous soils from phyllite residual soil.

Methodology for Remolded Treated Sample

Micro-bacteria from agriculture waste are obtained from the fermentation process of mix vegetables such as *Cucumis sativus*, *Ipomoea aquatic* and *Vigna unguiculata* subsp.*sesquipedalis* [16]. Liquid extracted from fermented mixed vegetable waste are name as vege-grout and these vege-grout produce micro-bacteria name as *Bacillus pasteurii* and *Bacillus Subtilis* [16]. Micaceous soil are collected using tube sampler technique and each 200gm micaceous soil are mixed thoroughly in different incremental percentages 15.0%, 17.5%, 20.0% and 22.5% of vege-grout toward the weight of micaceous soil to form remolded sample.

Treated remolded sample for optimum content determination are conduct using Uniaxial Compressive Strength Test (UCS). The sample are prepared using cylindrical PVC pipe sized 40 mm diameter and 70 mm height. The treated sample are filled into the PVC pipe and each 30 mm of soil filing will be compacted using rod by free fall at the height of 100 mm above the upper soil layer with 3 blows.

However, cylindrical stainless steel soil sampling tube with 38 mm diameter and 70 mm height are used for triaxial test. While, treatment sample for permeability test has been remolded using a 100 mm diameter and 120 mm height cylinder. All remolded micaceous samples either treated and non-treated are prepared based on the requirement of the testing procedure as [17]. The remolded treated and un-treated or control sample later are curing in room temperature for 7, 14, 21, 28, and 35 days before conducted the laboratory test. Fig. 1 shows the process of sampling and preparation of remolded micaceous samples.

Optimum content determination are conduct immediately after the index test and the curing time achieve 10 days to determine the percentage of vege-grout to be used for treatment of permeability and strength of micaceous soil.

![Figure 1. Preparation process of remolded micaceous treated sample from shallow landslide](image)

Result and Analysis

Micaceous soil from UNITEN site are classified as sandy SILT with intermediate plasticity. The liquid limit of the soil is 38.38% which is ranging from 30% to 50% and is classified as inorganic silts. These soil have medium compressibility that lies under the A-line plasticity chart. The liquidity index ($LI$) of the soil and the relative consistency of a cohesive soil in natural state is equal to -0.31 which is less than 1. When $LI < 1$, the soil are classified as heavily consolidated with plastic limit higher than the natural water or moisture.
content. The soil is well graded and has high percentage of fine grained particles amount as 63.76% and having larger pore space. Index test result for micaceous soil shows as Table 1.

| Properties                          | Value  |
|-------------------------------------|--------|
| Soil Type                           | Sandy SILT          |
| Group Symbol                        | 2.82    |
| Gravel Fraction (%)                 | 33.45   |
| Sand Fraction (%)                   | 63.74   |
| Silt Fraction                       | 19.74   |
| Coefficient of uniformity, $C_u$    | 2.75    |
| Coefficient of gradation, $C_c$     | 2.71    |
| Liquid Limit, LL (%)                | 38.38   |
| Plastic Limit, PL (%)               | 30.88   |
| Plasticity index, PI               | 7.5     |
| Liquidity Index, LI                 | -0.13 (<1)         |
| Moisture content, w (%)             | 29.9    |

Table 1. Index Test for micaceous soil

Optimum content of vege-grout to be used in micaceous soils are observe through the UCS test done after 10 days of curing using 15.0%, 17.5%, 20.0% and 22.5% of vege-grout. Fig. 2 shows the stress-strain relationship of treated micaceous soil based on different percentage of vege-grout. Micaceous soils that have been treated with 20% vege-grout shows highest strength i.e. 56.83kPa while 51.11kPa for 17.5% vege-grout, 49.28kPa for 22.5% vege-grout and 16.67kPa for 15.0% vege-grout. It shows the optimum content to improve 200gm micaceous soil need minimum content of 20% vege-grout. Detail observation as summarize in Table 2.

Figure 2. Unconfined compression strength of treated micaceous soil

| Vege-grout content (%) | Unconfined Compression Strength, $q_u$ (kPa) | Axial Strain at Failure (%) | Shear Strength at Failure, $\tau$ (kPa) | Consistency | Failure Type |
|------------------------|--------------------------------------------|----------------------------|----------------------------------------|-------------|--------------|
| 15.00                  | 16.67                                      | 0.27                       | 8.34                                   | Very Soft   | By Shearing  |
| 17.50                  | 51.11                                      | 0.81                       | 25.56                                  | Medium      |              |
| 20.00                  | 56.83                                      | 0.86                       | 28.42                                  | Medium      |              |
| 22.50                  | 49.28                                      | 0.76                       | 24.64                                  | Soft        |              |

Table 2. Summarize of unconfined compression strength test for treated micaceous soil

Falling head test are used for observation of permeability test. Five treated sample together with control sample are observed based on curing time 7, 14, 21, 28, and 35 days. The coefficient of permeability
value, $k$ of each sample are plotted as in Fig. 3 and Table 3 shows the typical $k$ values for different percentage of vege-grout. Control sample or untreated sample has $k$ value of $7.72 \times 10^{-4}$ mm/s. These micaceous soil is classified as semi-pervious of relative permeability and in group of silt and layered clay.

**Table 3. Summarize of permeability test for untreated and treated micaceous soil**

| Curing Time | Coefficient of permeability, $k$ (mm/s) | Percentage of improvement (%) | Percentage different from preceding (%) | Relative Permeability |
|-------------|----------------------------------------|-------------------------------|------------------------------------------|-----------------------|
| Control     | $7.72 \times 10^{-4}$                 | N/A                           | N/A                                      | Semi - Pervious       |
| 7 days      | $7.62 \times 10^{-4}$                 | 1.30                          | 1.30                                     |                       |
| 14 days     | $7.21 \times 10^{-4}$                 | 6.61                          | 5.31                                     |                       |
| 21 days     | $6.68 \times 10^{-4}$                 | 13.47                         | 6.86                                     |                       |
| 28 days     | $6.51 \times 10^{-4}$                 | 15.67                         | 2.20                                     |                       |
| 35 days     | $6.43 \times 10^{-4}$                 | 16.71                         | 1.04                                     |                       |

**Figure 3. Coefficient of permeability for treated and untreated micaceous soil**

Result shows decreasing pattern for the coefficient of permeability for treated micaceous soil. The peak of the improvement is after 21 days of mixing with vege-grout which is 13.47% from original soil. The different of the improvement from 14 days treated micaceous soil is 6.68% and the increment percentage from preceding samples slowly decrease by 2.2% and 1.04% for 28 days and 35 days micaceous soil respectively. Thus, the treatment process using vege-grout for permeability is optimum for 21 days and the permeability of soil started to stable between 21 to 28 days. Based on results, show the minimum optimum curing time for bio-cementation process is 21 days for micaceous soil. The improvement of permeability for treated micaceous still continued after 21 days but the rate is slow compare before 21 days. Fig. 4 illustrates the consistency of vege-grout treatment as bio-cement based on curing time lapsed together with the percentage of permeability improvement of treated soil based on curing time elapsed. Fig.4 shows the treated micaceous soil decreases the permeability from $7.72 \times 10^{-4}$ mm/s to $6.43 \times 10^{-4}$ mm/s with 16.71% of improvement rate. The $k$ value for treated micaceous soil are classified as semi-pervious of relative permeability and towards the pervious category. It means that the optimum permeability rate for 200gm micaceous soil treated with 20% of vege grout will give the increment of 16.71% of improvement rate.
Triaxial test are performed using Consolidated Drained (CD) method because the micaceous sample are fine grained soil. Consolidated Drained (CD) test are conducted using 100, 200 and 300kPa and in these paper the discussion are focused on the comparison between untreated and treated soil in maximum deviator stress, cohesion, friction angle and shear strength of the soils based percentage of vege-grout treatment and curing time elapsed. The maximum deviator stress of each cell pressure used increase and similar to cell pressure become higher after the treatment. The minimum optimum curing time for vege-grout treatment for micaceous soil based on the maximum deviator stress data is 21 days. Fig. 5 shows the result for maximum deviator stress value of 100kPa, 200kPa, and 300kPa of cell pressure and percentage of soil improvement in term of maximum deviator stress based on curing time elapsed.

Micaeous sample treated using vege-grout shows the incremental of cohesion and the friction angle toward the curing time. The incremental of cohesion and the friction will improved the soil consistency and density, thus increasing the shear strength of the soil. The $c'$ and $\phi'$ values of the soil were increased by 117.77% and 31.53% after curing 35days compared to original micaceous soil as shows in Fig. 6 and Table 4. Whereas, for 21 days curing are 65.54% and 30.56% for $c'$ and $\phi'$. 
Figure 6. Result for maximum deviator stress of cell pressure and percentage of soil improvement in term of maximum deviator stress based on curing time elapsed.

Table 4. Shear improvement for treated micaceous sample

| Curing Time | Cohesion, $c'$ (kPa) | Friction Angle, $\phi'(\degree)$ | Percentage of Improvement in Cohesion (%) | Percentage of Improvement in Friction Angle (%) |
|-------------|---------------------|----------------------------------|------------------------------------------|-----------------------------------------------|
| Control     | 15.93               | 13.32                            | N/A                                      | N/A                                           |
| 7 days      | 25.41               | 13.40                            | 59.51                                    | 0.60                                          |
| 14 days     | 25.11               | 15.53                            | 57.63                                    | 16.59                                         |
| 21 days     | 26.37               | 17.39                            | 65.54                                    | 30.56                                         |
| 28 days     | 32.70               | 17.44                            | 105.27                                   | 30.93                                         |
| 35 days     | 34.69               | 17.52                            | 117.77                                   | 31.53                                         |

Shear strength for micaceous treated soil using 20% vege-grout shows the improvement after seven days of curing period. The shear strength of treated micaceous soil increase toward the curing time as Fig.7. Shear stress on the failure plane of 20% vege-grout mixed with micaceous soil for 21 days curing are 57.69kPa, 89.01kPa and 120.33kPa and shear stress on the failure plane for 35days are 66.26kPa, 87.83kPa and 129.39kPa respectively to 100kPa, 200kPa and 300kPa. Percentage of improvement for 21days are 45.66%, 40.65% and 38.37% while percentage improvement for 35days are 67.29%, 54.59%, and 48.80% respectively to 100kPa, 200kPa and 300kPa as Table 4.

Table 5. Percentage of improvement in shear strength

| Curing Time | Percentage of improvement in shear strength respected to effective normal stress, $\sigma'_1$ (%) |
|-------------|-------------------------------------------------------------------------------------------------|
|             | 100kPa                                                                                         | 200kPa                                                                 | 300kPa                                                                 |
| Control     | N/A                                                                                           | N/A                                                                       | N/A                                                                 |
| 7 days      | 24.31                                                                                         | 15.45                                                                 | 11.41                                                                 |
| 14 days     | 33.56                                                                                         | 27.51                                                                 | 24.75                                                                 |
| 21 days     | 45.66                                                                                         | 40.65                                                                 | 38.37                                                                 |
| 28 days     | 61.88                                                                                         | 50.96                                                                 | 45.98                                                                 |
| 35 days     | 67.29                                                                                         | 54.59                                                                 | 48.80                                                                 |

Figure 7. Shear stress and percentage of improvement of shear stress toward curing time
Scanning Electron Microscope (SEM) indicate that there are change of soil structure caused by the development of bacteria during the curing time. The crystallization occur within the grain size and partially filled the pores. The development of calcite cementation induced by *Bacillus pasteurii* and *Bacillus Subtilis* called as bio-cement. The calcite cementation and the crystallization of calcite are show in Fig.8 as results from Energy Dispersive X-ray analysis (EDX). The EDX results shows the composition of $\text{Ca}_2\text{CO}_3$ occur as indicated by red in color and the cementation of calcite shows in reddish black.

![Figure 8](image.png)

**Figure 8.** Energy dispersive X-ray analysis (EDX) with 5 $\mu$m for calcite indication

Fig.9 shows the analysis result of Scanning Electron Microscope (SEM) with the identification of micro-bacteria as show in red line and namely as *Bacillus pasteurii* and *Bacillus Subtilis*. It shows that the 20.0% of vege-grout treated with micaceous soil curing for 21 days are crystallize to form cement between the grain and it made by *Bacillus pasteurii* and *Bacillus Subtilis*. The control sample show kaolinite occur as result from the weathering of mineral mica in phyllite and the microstructure of kaolinite with layer are cement after treated with vege-grout as shows by all treated sample in Fig. 9.

The percentage increment of permeability and shear strength of the micaceous soil treated with 20% vege-grout increase because of the modification of soil structure between the grain sizes. The significant of the percentage of increment for cementation by curing time are show in Fig. 9. The micaceous soil grain particles start to well cemented in 21 days and the crystallization process are continue to develop to form more calcite in between the grain. This crystallization and cementation influence to the increment of percentage of permeability and shear strength. The crystallization occur within the grain size and partially filled the pores and subsequently decreasing the void ratio and the permeability of the micaceous soil. The curing time give more influence to shear strength because the more the curing time give more strength to the treated sample.

![Image](image.png)

7 days 14 days 21 days
Concluding Remarks

*Bacillus pasteurii* and *Bacillus Subtilis* from the mixed vegetable waste can be used for micaceous soil treatment. The optimum content for mixing with the micaceous soils based on UCS test are 20% from 200gm of soil sample. These micaceous soil are classified as sandy SILT shows the percentage permeability increment of 16.71% for 21days curing. Shear stress on the failure plane of 20% vege-grout mixed with micaceous soil for 21 days curing are 57.69kPa, 89.01kPa and 120.33kPa. Scanning Electron Magnetic (SEM) shows that the modification of physical structure of soil particle because of cementation process from induce of micro bacteria influence to increment of percentage of permeability and shear strength.

In conclusion, the *Bacillus pasteurii* and *Bacillus Subtilis* from the mix of *Cucumis sativus*, *Ipomoea aquatic* and *Vigna unguiculata subsp. sesquipedalis* can be used to improve the micaceous soil. The result of this research thus are used as reference for enhancement of the injection technique to site scale and for treatment of others type of problematic soil.

Acknowledgement

This study is being supported through UNITEN seed fund (J510050613) as continuity project from ERGS grant entitle Selection and Application of Micro Bacteria from Agricultural Waste as Bio-Grout (13012011ERGS). Authors would like to thanks all under graduates, postgraduate and research engineer that give support during our observation in laboratory and site.

References

[1] E.M. Frempong 1994. Geotechnical Properties of Some Residual Micaceous Soils in The Kumasi Metropolitan Area, Ghana. Bulletin of the International Association of Engineering Geology, (49),1, 47-54

[2] Tan Boon Kong & Siti Farah Ezdiani Bt. Miasin @ Awang 2005. Physico-Chemical Properties Of Residual Soils Of The Kenny Hill Formation In The Shah Alam Area, Selangor Geological Society Of Malaysia Bulletin 51 June 2005 P.J3-17

[3] Widdows, J. & Brinsley, M. 2002. "Impact of biotic and abiotic processes on sediment dynamics and the consequences to the structure and functioning of the intertidal zone." Journal of Sea Research 48(2): 143-156.

[4] Comoss, E.J., Kelly, D.A., Leslie, H.Z., 2002. Innovative erosion control involving the beneficial use of dredge material, indigenous vegetation and landscaping along the Lake Erie Shoreline. Ecol. Eng. 19 (3), 203–210.

[5] Jones, K., Hanna, E., 2004. Design and implementation of an ecological engineering approach to coastal restoration at Loyola Beach, Kleberg County, Texas. Ecol. Eng. 22 (4–5), 249–261

[6] Fan, C.-C., Su, C.-F., 2008. Role of roots in the shear strength of root-reinforced soils with high moisture content. Ecol. Eng. 33 (2), 157–166

[7] Normaniza, O., Faisal, H.A., Barakbah, S.S., 2008. Engineering properties of *Leucaena leucocephala* for prevention of slope failure. Ecol. Eng. 32 (3), 215–221.

[8] Karol, R.H. 2003. Chemical grouting and soil stabilization. New York, Dekker.
[9] Leon A. van Paassen,*, Claudia M. Daza, Marc Staal a, Dimitri Y. Sorokina, Willem van der Zonb, Mark. C.M. van Loosdrecht, 2010. Potential soil reinforcement by biological denitrification Ecological Engineering 36, 168–175

[10] Dejong, 2006. Microbially Induced Cementation To Control Sand Response to Undrained Shear. Journal of Geotechnical and geoenvironmental

[11] Kim, Daehyeon, Park, Kyungho 2013. Injection Effect of Bio-Grout for Soft Ground Advanced Science Letters, (19), 2, 468-472(5). American Scientific Publishers

[12] Volodyymyr Ivanov, Jian Chu, Viktor Stabnikov 2012. Iron- and calcium-based biogrouts for porous soils, Proceedings of the ICE - Construction Materials, Volume 167, Issue 1, November 2012 pages 36 –41 DOI: 10.1680/coma.12.00002

[13] M.A. Van, G.A. van den Ham, M. Blauw, M. Latil, N. Benahmed, P. Philippe 2011 Preventing Internal Erosion Phenomena with the BioGrout process Pages 1079 – 1084 DOI 10.3233/978-1-60750-801-4-1079 Ebook Proceedings of the 15th European Conference on Soil Mechanics and Geotechnical Engineering

[14] Van Paassen, L.A., Pieron, M., Mulder, A., Van der Linden, T.J.M., Van Loosdrecht, M.C.M., Ngan-Tillard, D.J.M. 2009. Strength and deformation of biologically cemented sandstone. In: Vrkljan (ed.) Proceedings of the ISRM Regional Conference EUROCK 2009 - Rock Engineering in Difficult Ground Conditions - Soft Rocks and Karst, pp. 405–410, Dubrovnik, Croatia, 29–31 October.

[15] Kim Huat, Bujang and Keykya, Hamed A. and Asadi, Afshin and Kawasaki, Satoru 2012. Electro-Biogrouting and Its Challenges. International Journal of Electrochemical Science, 7 (2012). pp. 1196-1204. ISSN 1452-3981

[16] Rohayu Che Omar, Rasyikin Roslan, Intan Nor Zuliana Baharuddin, Lariyah Mohd Sidek and Fathoni Usman (2013). Vege-grout for soil and rock remediation process. PI 2013701380. Intellectual Property Corporation of Malaysia.

[17] BS 1377-7 1990. Methods of test for soils for civil engineering purposes. Shear strength tests. British Standard Institute.