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STRENGTH IMPROVEMENT OF SAND TREATED BY BIOCEMENTATION PROCESS AND HEMP FIBER

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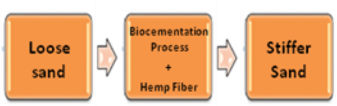
Graphical abstract



Abstract

This article presents the green technology using biocementation process to initiate the crystal forms of carbonates to bind the soil particles resulting in soil mechanical improvement. This research examines the feasibility of microorganisms capable of hydrolyzing urea with production of carbonate collected from natural and agricultural soils. The biocement was prepared by a mixture of calcium salt, urea, and microbial suspension extracted from collected soil samples. The calcium crystal forming shapes was studied. This research measured the ammonification rate in biocemented process. Non-destructive testing method using shear wave velocity was applied for strength measurement in sand mixed with hemp fiber of 0.5 1.0 2.5 5.0 10.0 and 20.0% by volume. The optimum hemp fiber of 2.5% was found and formation of calcite layer on sand surface could be useful for the stabilization of the sand or earth structures.

Keywords: Biocementation process, ground improvement, sand

1.0 INTRODUCTION

Current soil improvement techniques, i.e. the usage of cement and chemical additions, use large amount of energy and man-made materials, these create environmental concerns. Recently, the new technique using microbial biotechnology for producing biocement is being interest due to environmentally friendly, low-energy input and also microorganisms used in the process are non-pathogen. Furthermore, unlike the use of cement, soils in the fields can even be treated or improved without disturbing the ground or environment as microorganisms can penetrate and reproduce themselves in the soil naturally. It has been reviewed that some microorganisms i.e. *Bacillus sp.* and *Sporosarcina sp.* in the medium contained urea and calcium ion can induce precipitation of calcite [3, 4, 8, 9]. Bacteria produce enzyme urease that hydrolyzes urea (Eq. 1) to ammonium and carbonate. Production of ammonium resulted on the increase of pH and formation of calcium carbonate ($CaCO_3$, Eq. 2), which filling the pore space and increasing solid content in soil [2, 5]. However, the question of which microorrganism types are the most effective at biocementation is equally important, but has not yet been thoroughly studied. Utilizing different types of microorganisms may result in different rate of calcite formation in soil. In this research, the source of urea degrading bacteria was originated from natural water (Chaophraya River, Thailand), where the bacterial community is mixed cultures.

$$CO(NH_2)_2 + 2.H_2O \xrightarrow{\text{Urease}} 2.NH_4^{+} + CO_3^{2-} \quad [1]$$

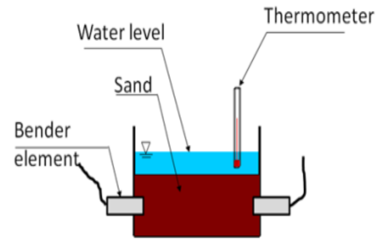
$$Ca^{2+} + CO_3^{2-} \longrightarrow CaCO_3 \quad [2]$$

Shear waves (S-waves), the 2nd mode of propagation, in which the direction of particle motion is perpendicular to the direction of propagation and it is recently used for measuring the relative strength in soil [7]. Advantages of this application are a non-destructive method and are capable to measure the soil strength in function of time. Thus, it can be applied in the field for measuring the changes of ground improvement conditions in the long period. Recently many researches are studied the application of non-destructive testing for measuring shear wave velocity and shear modulus but few researches are found in biological soil improvement applications. This research measured the ammonification rate in biocemented process. Non-destructive testing method using shear wave velocity was applied for strength measurement in loose sand.

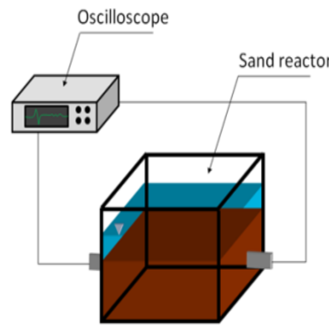
2.0 METHODOGY

2.1 Sand Reactors

The sand reactors (SR) was made of plastic containers with dimensions of 80 x 80 x 80 mm (width x length x height). The reactors were replaced with sieved sand (passed no. 100 and retained no.200) with an approximate depth of 40 mm. Figures 1a and 1b show the design and setup of SR in a laboratory. Sand sample was introduced into SR and filled with 300 mL of nutrient solution contained 250 mM of urea, 250 mM of calcium ion (by $CaCl_2$), and glucose of 1.5mM. Source of water used for preparing the solution was collected from Northern part of Chaophraya River. The experiment was performed in ambient condition with average temperature of 25 ± 2 °C. The water level of each reactor was re-marked. An addition of deionized water to each SR was sometimes needed to maintain the constant level of water table and prevent the level falling due to water loss by evaporation.



(a)



(b)

Figure 1 Sand reactors (SR): (a) Setup of SR and (b) Installation of bender element and oscilloscope for monitoring the strength development

2.2 Hemp Fiber

Natural fiber was used in this research was hemp fiber. This hemp fiber has been used widely all over history, with industrial production ranging from rope to fabrics. Hemp was often used to make sacks. So hemp fibers are cut from industrial hemp sacks. Figure 2 showed hemp fibers which are approximately cut with 1 cm in length and dried in the oven with 80 °C for 24 hours.

Figure 2 Hemp fiber

2.3 Bender Element Test

Recently, the research develops the new test set-up for measurement of the shear wave velocity, V_s, by means of elastic shear wave propagation. This new test uses the principle of wave propagation through soils as described in [6]. This shear wave velocity is an important parameter in earthquake engineering and the prediction of soil structure interaction. The shear wave is generated and received by piezoelectric ceramic sensors placed at opposite ends of the soil sample. The shear wave velocity is calculated from the tip to tip distance between the two sensors and the time required by the shear wave to cover this distance and time as shown in Eqs. 3 and 4.

$$V_s = \frac{L}{t} \quad [3]$$

$$t = t_t - t_c \quad [4]$$

where V_s is the shear wave velocity, L is the tip to tip distance between two sensors. t is the required time to cover this distance, t_t is the total travel time and t_c is the offset time.

The initial shear modulus (G_0) can be calculated by Eq. 5.

$$G_0 = \rho \times V_s^2 \quad [5]$$

where ρ is the sand density. Figure 3 shows the schematic test set-up.

A personal computer generates a signal through a sound card with 5V peak to peak as suggested by [6]. This signal is amplified to 40V peak to peak. An oscilloscope is used to measure the arrival time between a sending signal and a receiving signal. A voltage pulse is applied to the sending sensor, this causes it to produce a shear wave. When the shear wave reaches the other end of the soil sample, distortion of the receiving sensor produces another voltage pulse. The receiving sensor is directly connected to the oscilloscope to compare the difference in time between the sending and the receiving signals. The shear wave velocity measurements are usually performed with frequencies ranging between 2 to 12 kHz, at strains estimated to be less than 0.0001 %. At low frequencies, signals can be influenced by a near-field effect. At high frequencies, the receiving signal is very weak and difficult to interpret. In most cases, signals are averaged 32 times in order to get a clear signal. The measurement of shear wave velocity in soil sample by means of piezoelectric ceramic sensors is clearly described by [7].

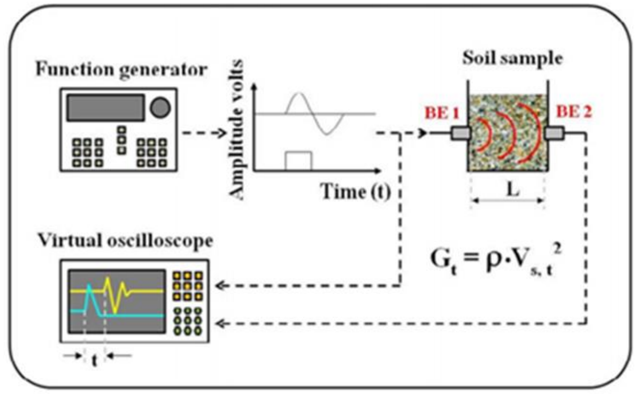


Figure 3 Schematic of bender element test set-up

2.4 Analytical Procedures

Treated sands (SR1 and SR2) were measured for strength development by bender element technique. Sand samples were collected for observing the morphology by scanning electron microscope (SEM) and analyzed by X-ray diffraction (XRD). Effluent water was sampled and analyzed for ammonium production (NH_4^+). The water pH was measured by a pH meter. These parameters were conducted through the period of the experiment and the analyses were based on the procedures of Standard Methods for the Examination of Water and Wastewater [1].

3.0 RESULTS AND DISCUSSION

3.1 Ammonification Rate and Change of pH Results

Figure 4 illustrates the formations of NH_4^+ produced by biocemented (SR) treatment. The production rate of NH_4^+ distinctly increased in SR after a week of experiment. The NH_4^+ production rate in SR was rapidly increased from 0 at day 0 mg L^{-1} d^{-1} to about 4500 mg L^{-1} d^{-1} at day 4 and dropped to 2000 to 3400 mg L^{-1} d^{-1}. The high NH_4^+ concentrations were found by biocemented treatment due to the decomposition of urea added in the solution, while small NH_4^+ production by control treatment might result from the decomposition of residual Org. N matter of only sand origin. The line graph in Figure 5 shows the change of pH in SR. Higher production of NH_4^+ could result on higher alkalinity and pH in SR as demonstrated in Eq. 1.

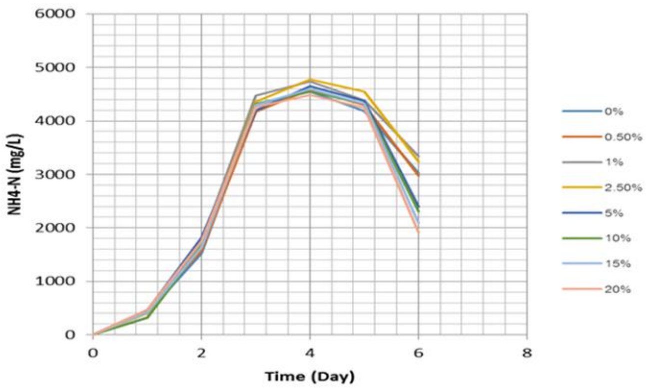


Figure 4 NH_4^+ production rate in biocemented (SR) treatment

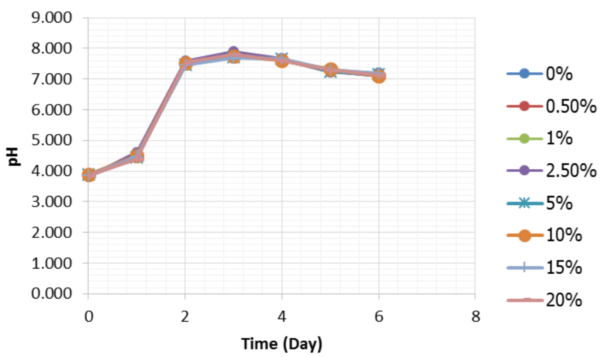


Figure 5 Change of pH in biocemented (SR) treatment

3.2 X-Ray Diffraction Results

Figure 6 reported the different pattern of X-Ray Diffractogram. The different peaks between the typical and the treated sands in comparison with only precipitated $CaCO_3$ in solution are marked by "symbol ▲" while the "symbol ●" marked the increment of chemical compositions in sand samples. This result ensured that the precipitated $CaCO_3$ was occurred inside treated sand sample (SR). The occurrence of the precipitated $CaCO_3$ may explain by the biological degradation of urea generating CO_3^{2-} (soil microbial respiration) and OH^- resulting an increasing of pH and later precipitating of $CaCO_3$ in sand layer [3].

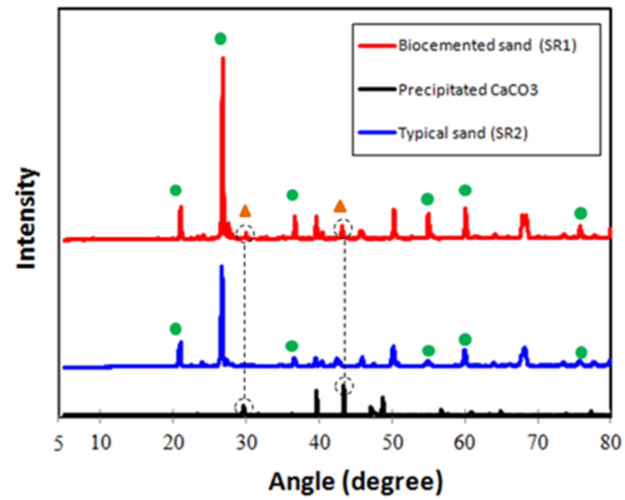


Figure 6 Pattern differences of X-ray diffraction between typical sand and treated sand after biocementation ("▲" indicates the precipitated $CaCO_3$ in sand and "●" indicates the increment of further chemical compositions)

3.3 Bender Element Results

Figure 7 shows all shear wave velocity results of sand mixed with hemp fiber of 0.5 1.0 2.5 5.0 10.0 and 20.0% by volume after biocement process. From the results, the Vs are about 80 m/s at day 0, then at day 2 the Vs are fast increased and constant at day 4. The Vs result of 2.5% hemp fiber was 600 m/s. The V_s result of 1.0% hemp fiber was about 500 m/s while the rest results are about 400 m/s. In the similar way, the G_0 result of 2.5% hemp fiber was 500 MPa. The G_0 result of 1.0% hemp fiber was about 340 m/s while the rest results are about 240 m/s. So, the optimum percent hemp fiber is 2.5% as shown in Figure 8.

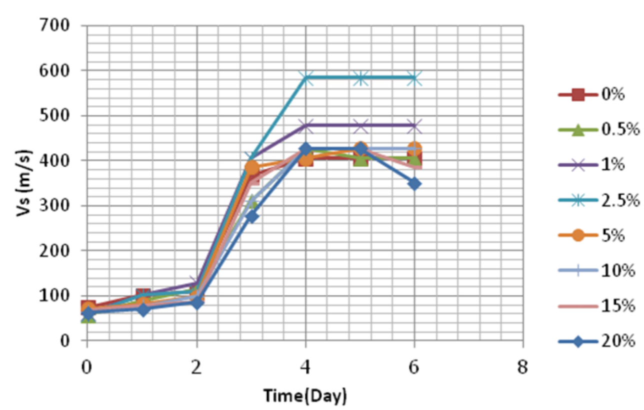


Figure 7 Change of V_s in biocemented (SR) treatment

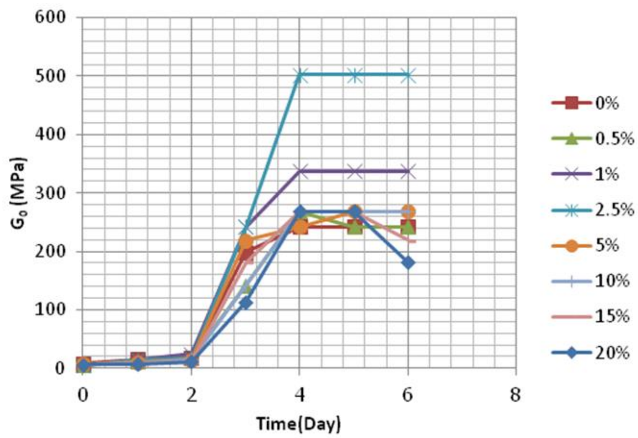


Figure 8 Change of G_0 in biocemented (SR) treatment

4.0 CONCLUSION

Biocementation is continuous process for strength development in soil through the biological formation of $CaCO_3$. Application of shear wave velocity can be used to measure its strength over time and without destruction of soil sample. Analytical results from XRD ensured the occurrence of $CaCO_3$ in treated sand under biocemented process. The measurement of shear wave velocity in sand mixed with hemp fiber of 2.5% by volume shown that it was the optimum ratio.

Acknowledgement

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References

[1] APHA, AWWA and WEF. 2012. *Standard Methods For The Examination Of Water And Wastewater*. 22th Eds. Washington, DC: American Public Health Association, American Water Work Association and Water Environment Federation.

[2] Castanier, S., Le Méteyer-Levrel, G. And Martire, L. 2000. Bacterial Roles In The Precipitation Of Carbonate Minerals. *Microbial Sediments*. 32-39.

[3] De Jong, J. T., Mortensen, B. M. Martinez, B. C. And Nelson D. C. 2010. Bio-Mediated Soil Improvement. *Ecol. Eng*. 36: 197-210.

[4] De Jong, J. T., Soga, K., Ian, E. K., Burns, S., Van Paassen, L. A., Qabany, A. A.,Aydilek, A., Bang, S. S., Burbank, M., Caslake, L. F., Chen, C. Y., Cheng, X., Chu, J., Ciurli, S., Esnault-Filet, A., Fauriel, S., Hamdan, N., Hata, T., Inagaki, Y., Jefferis, S., Kuo, M., Laloui, L., Larrahondo, J., Manning, D. A. C., Martizez, B., Montoya, B. M., Nelson, D. C., Palomino, A., Renforth, P., Santamarina, J. C., Seagren, E. A., Tanyu, B., Tsesarsky, M. And Weaver, T. 2013. Biogeochemical Processes And Geotechnical Applications: Progress, Opportunities And Challenges. *Géotechnique*. 63: 287-301.

[5] Ivanov, V. And Chu, J. 2008. Application Of Microorganisms To Geotechnical Engineering For Bioclogging And Biocementation Of Soil In Situ. *Rev. Environ Sci Biotechnol*. 7: 139-153.

[6] Mohsin, A. K. M. And Airey, D. W. 2003. Automating G_{max} Measurement In Triaxial Tests. *Proc. Prefailure Deformation Characteristics of Geomaterials, Lyon*. 73-80.

[7] Piriyakul, K. 2010. A Development of A Bender Element Apparatus. *Journal Of King Mongkut's University Of Technology North Bangkok*. 20(2): 363-369. (Thai Journal).

[8] Piriyakul, K. And Iamchaturapatr, J. 2013. Biocementation Through Microbial Calcium Carbonate Precipitation. *Journal of Industrial Technology*. 9(3): 1-21. (Thai Journal).

[9] Van Paassen, L. A., Ghose, R., Van Der Linden, T. J. M., Van Der Star, W. R. L. And Van Loosdrecht, M. C. M. 2010. Quantifying Biomediated Ground Improvement By Ureolysis: Large-Scale Biogrout Experiment. *J. Geotech. Geoenviron. Eng*. 136: 1721-1728.