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Vege-Grout: A Potential Bio-Grout Material from Vegetable Waste for Bio-Cementation

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ABSTRACT

Several studies have reported that the calcite precipitation induced by ureolytic bacteria through the hydrolysis of urea was influenced by several important factors including the concentration of calcium ions, the surrounding pH and temperature. Recently, the microbial induced calcite precipitations (MICP) were further explored using natural elements and microorganisms from the environment. Vegetable waste provides the proper substrate for microorganism's growth and activities. In this study, the calcite forming ability of indigenous bacteria in the vegetable waste was investigated by mixing the extract of vegetable waste known as vege-grout with sandy soil. The vege-grout optimum content was determined by unconfined compression test to find the suitable ratio of vege-grout content. The results of this study showed that there was an increase of compressive strength after 28 days of curing with vege-grout. SEM and EDX analysis showed aggregation of soil particles and formation of calcium carbonate ($CaCO^3$). Microbiological analysis of vege-grout extract indicated the presence of ureolytic bacteria that could be responsible for the bio-cementation process. Analysis by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) showed that the vege-grout extract contained a rich source of carbon, nitrogen and calcium elements. This study has demonstrated the potential application of vegetable waste for microbial cementation of soil particles.

1. INTRODUCTION

Bio-mediated cementation of soil using microbial technology microbial has attracted many researchers in the branch of Geotechnical Engineering. This bio-mediated process is known as microbial induced calcium carbonate precipitation (MICP) that focused on 'bio-clogging' and 'bio-cementation' of soil particles (Chu J, et al 2014). Bio-clogging refers to the process of filling soil void by the bio-mechanism products of

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microorganisms such as biomass and exopolymeric substances that can reduce the permeability of soil by restricting the water flow in the soil. Bio-cementation refers to the binding of soil particles through the mineralization or precipitation process of microbial activities that help improve the shear strength of soil (Ivanov, V. and Stabnikov, V., 2017). The application of this new microbial technology has been explored in many areas such as the improvement of soil strength and impermeability, mitigation of soil liquefaction, concrete repair and lately, the making of zero cement bricks (Wang Z et al, 2017)(Achal, V. and Mukherjee, A., 2015).

There are many factors that affect the performance of MICP. Among them are nutrients such as chemical elements that include N, C, Mg, Fe, Ca etc which are very important for the microorganisms to live and survive (Joshi, S., Goyal, S. and Reddy, M.S., 2018). Without these, the microorganisms will die or consume each other, and the bio-mechanism process will stop. For an effective calcite precipitation, the type of bacteria also plays a major role in the bio-cementation process (Graddy, C.M et al. 2018).Many studies have emphasized the use of ureolytic bacteria such as *Sporosarcina pasteruii,* to induce MICP through urea hydrolysis even though this can also be achieved by other bio-chemical pathways such as denitrification and sulphate reduction (Omoregie et al. 2017). Van Paassen et al. (2010) found that the production of calcite through urea hydrolysis was higher than the other processes. Particularly for urea hydrolysis and urease activity, pH and temperature also influence the MICP process. Alkaline environment is necessary to activate the urease enzyme. It was demonstrated that the urease activity was optimized at pH value ranged from 7.5 to 8.0. Optimum temperature for MICP application is also essential for bacterial growth. One study mentioned the optimum temperature for urease activity ranged from 10^{o}C and 60^{o}C (Khan et al. 2015).

Our research on vegetable waste or vege-grout has proved that substrate from vegetable waste can also replace the role of nutrient media and broth for bacterial growth by using the fermentation process. Fermentation actually increases the nutrient content of the vegetable waste and also promotes growth of variety of microorganisms (Tamang, J.P. et al. 2016). The concept of utilizing vegetable waste as a replacement will encourage recycling of waste products that can be converted to other useful resources. In this study, substrate of vegetable waste will be used to induce MICP. The effectiveness of this method was determined by measuring the shear strength of the treated soil samples. The formation of calcite or calcium carbonate was evaluated by Scanning Electron Microscope (SEM) and EDX analysis. The chemical elements such as Si, Fe and Ca in the vege-grout were analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

2. EXPERIMENTAL

2.1 Vege-grout preparation and analysis

Vegetable waste such as cabbage, long bean, cucumber and spinach were collected from various sources like the wet market and farmer market around the area and brought back to the laboratory. All the vegetables were washed and rinsed thoroughly using distilled water to avoid cross-contamination. Then the vegetables were cut into small pieces and kept in a clean container for fermentation process. The containers were tightly closed and kept for one month at room temperature. The pH of the vegetable was monitored once a week with a pH meter. The alkalinity of the substrate was maintained by adding urea throughout the fermentation process to promote the growth of ureolyic bacteria. The vegetable substrate gave a rotten smell and the color appeared brownish that was generated by microbial activities. After one month, the substrate was filtered, collected and transferred to another clean container for further analysis. Figure 1 showed the process of vege-grout preparation. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used to measure the amount of silica, iron and calcium elements in the vegetable substrate. These minerals play a major role for the bio-clogging and bio-cementation of soil particles through various bio-chemical pathways induced by the microorganisms. (Chu, J. and Ivanov, V., 2014). The substrate sample was also sent a certified microbiology lab to screen pathogenic bacteria.

Fig. 1 Vege-grout preparation

2.2 Determination of Vege-grout optimum content by UCS

The optimum content of vege-grout has to be determined first before any test for engineering soil properties is carried out. This was necessary to estimate the percentage of the vege-grout used in the soil mixture. The experiments were done by unconfined compression test (UCS). Four remoulded samples of different vege-grout mixture consisting of 15%, 17.5%, 20%, and 25% vege-grout were cured for 10 days and tested using the UCS test (Figure 2). The optimum vege-grout content will be determined from the highest compressive strength obtained. The UCS test followed the procedure in BS 1377-7: 1990. The soil in this study was classified as sandy SILT with intermediate plasticity from laboratory test for basic soil properties (data not included).

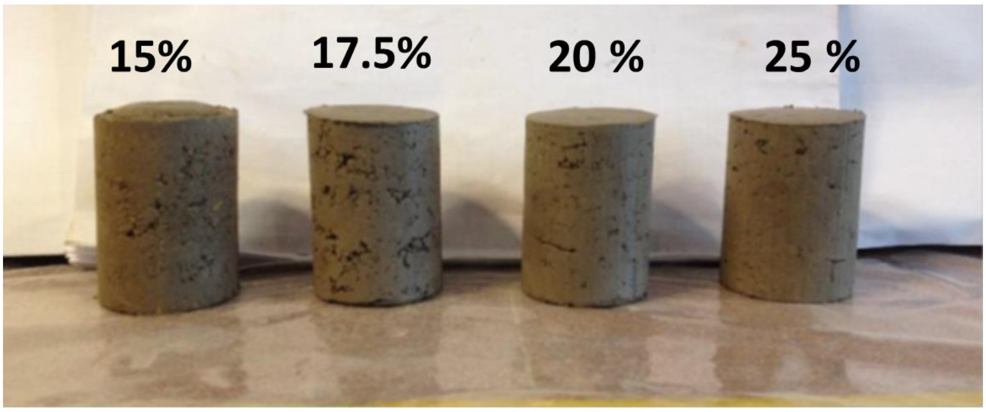

Fig.2 Remoulded samples containing vege-grout mixture

2.3 Determination of Shear Strength by Triaxial Test

Triaxial test was conducted by Consolidated Drained (CD) method to determine the shear strength. To fully complete the triaxial, 3 trials were carried out to establish the Mohr-Coulomb circle. The Mohr Circle and failure envelope can then be interpolated to obtain the shear strength; friction angle and the cohesion. The soil shear strength was tested following BS 1377-7:1990 Clause 5.5 guideline. Six series of triaxial tests were carried out comprising of original soil and treated soils based on curing period. In this work, 100, 200, and 300 kPa of cell pressures were used for every set of experiment. The analysis was focused on the comparison between original and treated soil in maximum deviator stress, cohesion, friction angle, and shear strength of the soils based on curing time elapsed of the vege-grout treatment.

3. RESULTS AND DISCUSSION

3.1 IC-MS and microbiological analysis

Analysis of IC-MS on the vege-grout showed that the vege-grout contained a high amount of chemical elements such as Si, Fe and Ca which are important for the MICP process. Apart of that, the substrate was also rich in Carbon and Nitrogen which are essential for bacterial growth (Table 1).

Table 1. Total of chemical elements in vege-grout

Sample	**Total silica (Si), iron (Fe) and calcium (Ca) (mg/L)**	**Carbon (C), (mg/mL)**	**Nitrogen (N), (mg/mL)**
Vege-grout extract	42.62389	253.414476	9236.268513

Microbiological analysis of the vege-grout showed a variety of bacterial species which can be found from the environment such as soil and water. The presence of coliform bacteria could be due to cross-contamination during the handling process. However, the amount of colony units was relatively small.

Table 2. Microbiological analysis of vege-grout

Test Parameter	Unit	Vege-grout	Test Method
Escherichia coli	CFU/100mL	<1	USEPA 1604
Salmonella	Present/Abse nt	Absent	IHM EWI-MB22
Staphylococcus aureus	CFU/100mL	<1	APHA 9213 B.6
Clostridium perfringens	CFU/100mL	<1	IHM EWI-MB13
Pseudomonas aeruginosa	CFU/100mL	1.3 x 10^4	APHA 9213 E
Fecal Enterococcus/Streptococcus Groups	CFU/100mL	2.3 x 10^3	APHA 9230 C

3.2 Determination of bio-grout content from UCS test

From the experiment, the 15% of vege- grout content was found not suitable for sandy silt soil since it had more percentage of fine grains. It can be concluded that the vege-grout optimum content for sandy silt soil was 20%. Figure 3 shows the failure of the soil samples by shearing, not bulging. Table 2 summarized the result of this test.

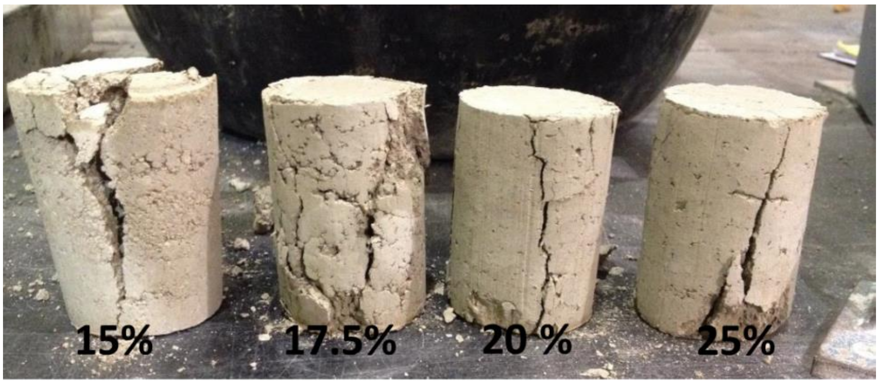

Fig.3 Failure of treated soil samples by shearing

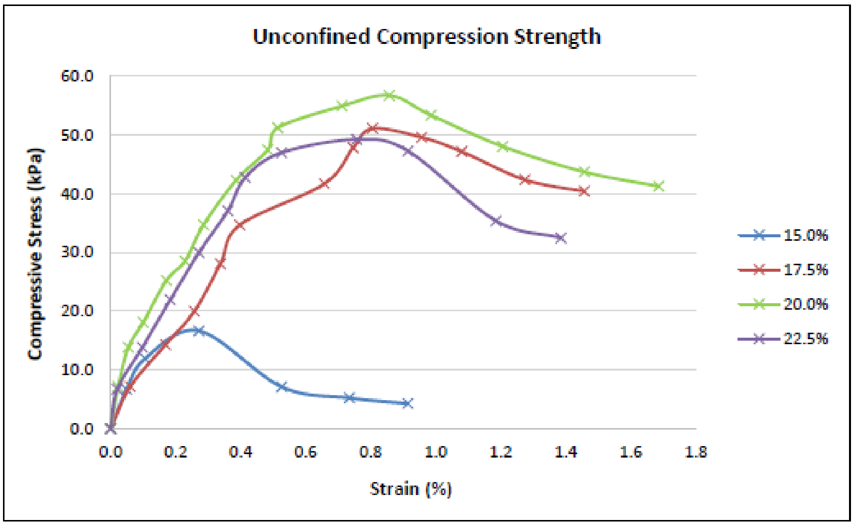

Fig.4 Unconfined compression strength of treated soil

3.3 Triaxial test

Maximum deviator stress

Results showed that the maximum deviator stress increased significantly as the curing time of vege-grout treatment increased. The relationship of maximum deviator stress for all samples is illustrated in Figure 3.

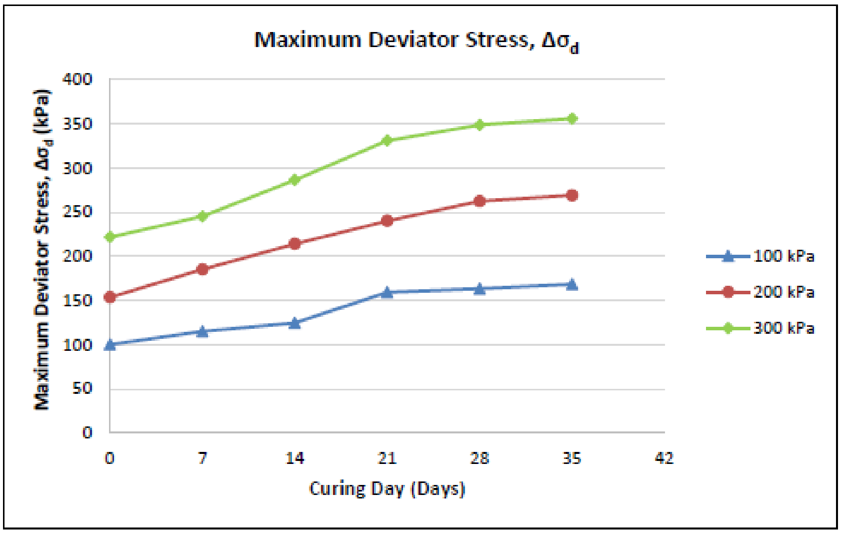

Fig.3 Maximum deviator of cell pressure based on curing period

Soil shear strength

The shear strength is a function of cohesion between the soil particles and frictional resistance between soil particles. In the triaxial test analysis, the two important parameters are obtained from Mohr's circles that is generated based on minor and major principal stresses which are in term of effective stresses. The effective stress is carried by the soil solids. Thus, the c' and ϕ' are the effective stress cohesion and effective angle of friction. Results showed that the cohesion and the friction angle of the treated soil have increased by 117.77% and 31.53% respectively as the curing period increased, which lead to the improvement of soil consistency and density (Figure 4).

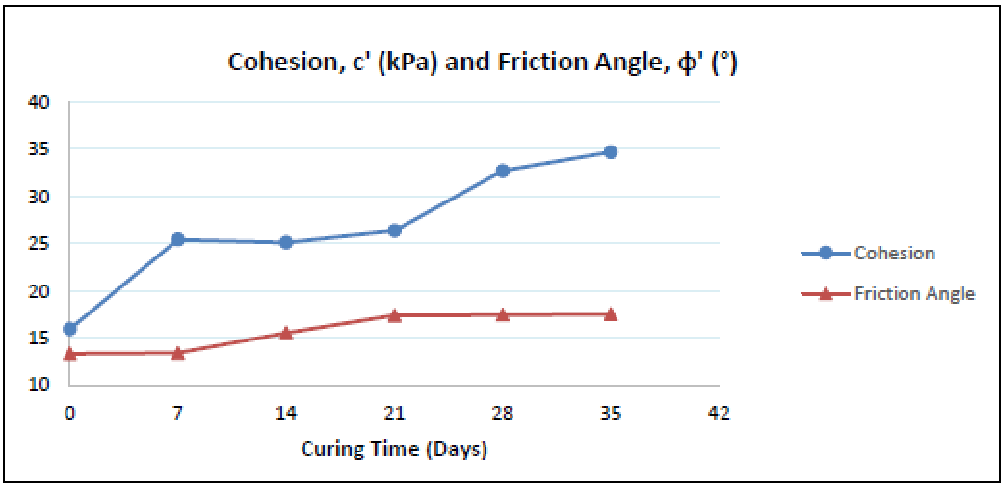

Fig.4 Improvement of shear strength parameters

From these parameters, the shear strength of the soil can be obtained by the Mohr-Coulomb equation. The shear strength is obtained at the failure plane based on respective normal stress. Figure 5 illustrates all the data and results of the calculated shear stress.

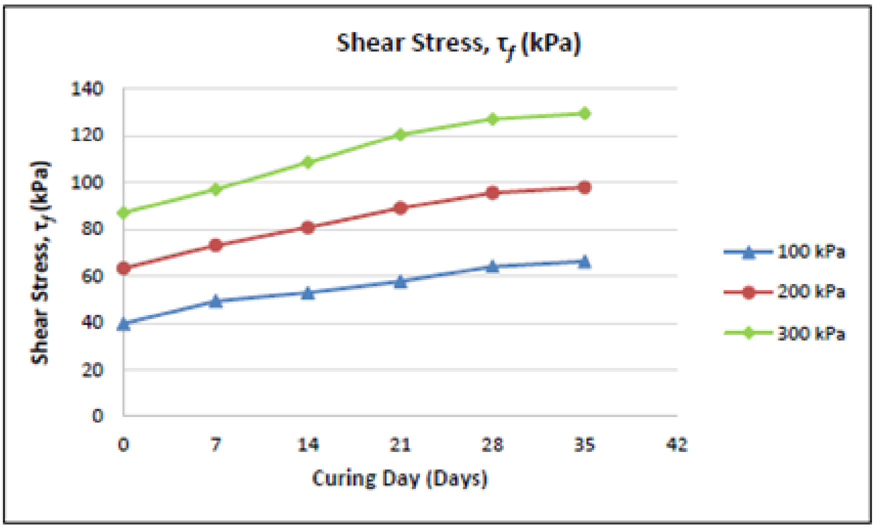

Fig. 5 Improvement of shear stress based on curing period

All the results showed that there are significant improvement in soil shear strength with respect to maximum deviator stress, effective stress cohesion, effective angle of friction and shear stress of the soil. Based on this consolidated drained triaxial test, the soil shear strength has showed significant improvement as curing period increased. This indicated that the aggregation of soil particles have somehow increased through microbial activities in the vege-grout. The same findings were also demonstrated in previous study that applied bio-grout treatment and carbonate precipitation (Kanayama M et al., 2012).

3.4 SEM and EDX analysis

The results of the SEM-EDX analysis showed the presence of elevated amount of calcium in the treated soil sample compared to that of the untreated sample. This indicates that the bio-cementation process based on precipitation of calcium carbonate ($CaCO_3$) has taken place through bio-mediated activities of microorganisms (Figure 6 and 7).

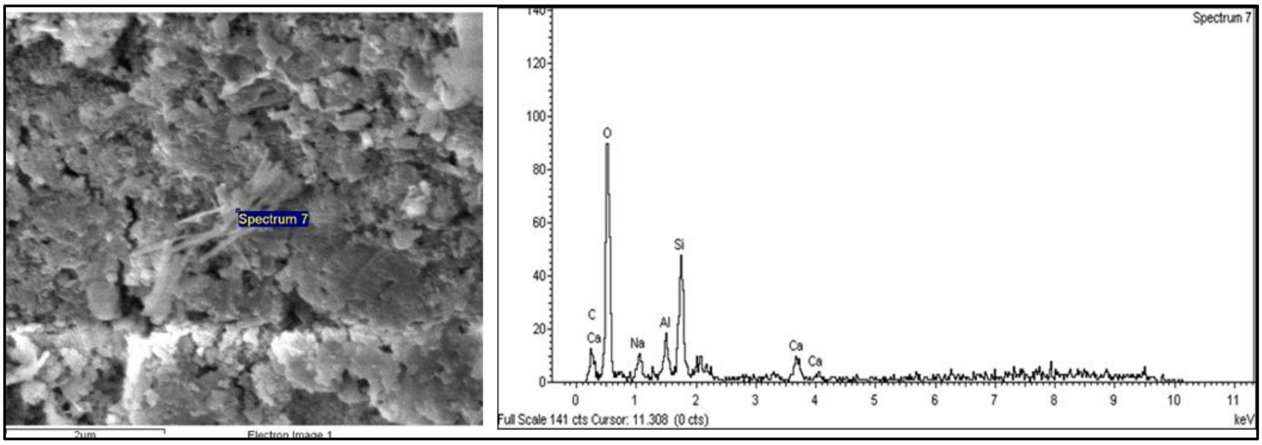

Fig. 6 SEM-EDX profile of untreated soil

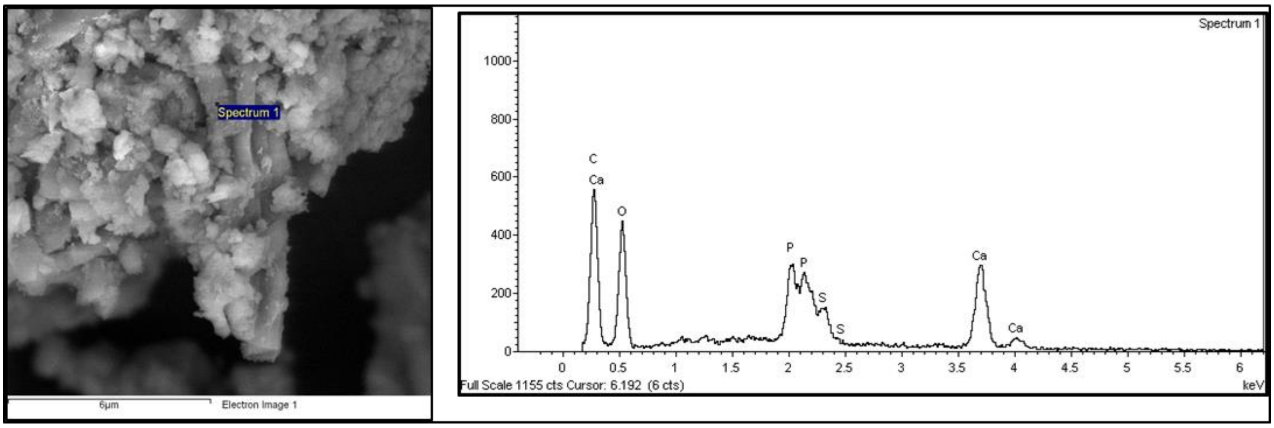

Fig. 7 SEM-EDX profile of treated soil with vege-grout

4. CONCLUSIONS

In this study, vegetable waste was processed using fermentation method to obtain a variety of microorganisms communities to induce MICP. Most research studies involving MICP application used cultivated bacteria and nutrient media or broths which were quite expensive and not suitable for large scale application. Apart of that, the vege-grout abstract was also rich in nutrients to ensure the survival and growth of the microorganisms. Here, it was demonstrated that vege-grout from vegetable waste was able to induce MICP by the evidence of calcite formation shown in the SEM-EDX analysis. The bio-cementation process has occurred resulting in the improvement of the soil strength. It can be concluded that vege-grout from vegetable waste can be used as a replacement for cultivated bacterial culture and nutrient media. This method is economical, promotes the usage of waste products and suitable for large-scale application in ground improvement method.

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