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RESEARCH ARTICLE

ENHANCING SOIL QUALITY VIA MICROBIAL TREATMENT WITH VEGETABLE WASTE AND THE INCLUSION OF POLYETHYLENE PLASTIC AS STABILIZING AGENTS

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Abstract. Microbial-induced calcite precipitation (MICP) is a well-known technique for soil stabilization utilizing microbes through biomineralization to improve soil engineering properties. This research emphasizes the potential use of fermented vegetables (vege grout) as sources of MICP microbes, not only for soil stabilization but also for the decomposition of Polyethylene (PE) plastic waste. The silty clayey soil type was treated with 15 %, 17.5 %, 20 %, and 22.5 % of vegetable grout liquid and cured for 35 days. The finding shows that the inclusion of 15 % vegetable grout reaches the highest strength of silty clayey soil type with 220 kPa shear strength after 35 days. The reduction in CBR value also demonstrated the improvement in the deformation behavior of soil after treatment. The SEM microstructural image shows the presence of Leuconostoc mesenteroides bacterium at an optimal level of 15 % vege grout additions after 35 days, leading to a new discovery in soil strengthening through the use of vege grout. Besides, the discoloration of PE plastic and the reduction of carbon content in soil from EDX analysis indicated the degradation of PE plastic. This result demonstrated that the utilization of vegetable and PE wastes had significant potential for preventing geotechnical engineering disasters which holds substantial importance from both economic and environmental perspectives in the future.

Keywords: Soil stabilization, vegetables grout, bio-cementation, PET plastic.

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1. INTRODUCTION

Generally, various soil reinforcement methods have been established in civil engineering for slope stability which are categorized as physical, mechanical, or chemical treatment. Much research is focussing on the combination of mechanical and chemical methods that were conventionally used for soil stabilization [1–3]. Some mechanical methods use fibrous materials with chemical methods by utilizing either enzymes, polymer resin, or several conventional materials such as bitumen, lime, and cement for soil improvement. The combination of PET plastic strips as reinforcement with soil binder, particularly on weak soil has a big potential to be a successful technique for soil stabilization. Mehdi et al. [4] investigated the compaction behavior of clayey soil using PET reinforcement and lime as a binder. Considering different shapes and ratios of PET plastic as reinforcing material in ranges from 0.5 % up to 2 % was able to enhance the strength of the soil. The existence of lime as a binder in the soil containing PET plastics reduced the fluctuation of sample strength and improved the mixture's rigidity. However, a widely debated aspect in the literature regarding the materials and methods employed for soil stabilization pertains to sustainability issues. Hence, this study emphasizes using a combination of vegetable waste as a binder and commercial plastic Polyethylene (PE) waste as soil stabilizers on slopes.

Polyethylene (PE) is a recyclable and easily manufacturable thermoplastic that is extensively utilized in packaging industries, domestic appliances, as well as for precision molding parts in office and automotive applications. Managing the substantial volumes of plastic waste poses a significant environmental challenge. Consequently, there is a notable emphasis on repurposing and reutilization of these plastic waste products across various applications including geotechnical applications. Islam et al. [3] use PET strip bottles as aggregate in concrete at the slope. The addition of PET coarse aggregate enhanced the compressive strength of the concrete as compared to the natural aggregate. On the other hand, PET fiber was also used as the soil reinforcement to provide more ductility, improve the shear strength, and avoid the formation of cracks [5]. The review done by Montazer et al. [6] stated that some species of bacteria found in agricultural waste areas, dumped soil areas, and municipal landfills were discovered to have the ability to degrade polyethylene (PE). Bacteria such as *Bacillus Species* and *Pseudomonas Species* were able to degrade the PE bags with 20 - 30 % of weight loss within 30 days or even more. Those bacteria convert this synthetic PE plastic into safe and non-toxic carbon compounds before leaching into the soil.

Montazer et al. [6] also stated that essential elements that may induce the colonization of bacteria and promote the degradation of PE plastics are the secretion of biosurfactant compounds. *Bacillus sp* are the bacterium that could produce this biosurfactant compound (surfactin). Moreover, this bacteria not only could degrade the plastics, but also promote soil stabilization through the microbially induced calcite precipitation (MICP) process [7] . During the MICP method, the microbial and biochemical activities induce the formation of calcium carbonate precipitation and undergo biomineralization in the soil. The enzymes generated by microorganisms, secrete (CO_3^{2-}) and react with (Ca^{2+}) in the environment resulting in the precipitation of minerals [8]. The precipitation of minerals binds the soil particles thereby enhancing soil strength. It is a non-pathogenic and endospore-producing bacteria in the environment at an alkaline pH for growth. The urease found in microorganisms such as bacteria, plants, fungi, algae, or even inside the soils was capable of inducing carbonate precipitation [9]. Recently, Omar et al. found the urease-producing bacteria *Bacillus Pasteuri,* and *Bacillus Subtilis* in fermented vegetable waste that was developed to be a soil stabilizer [10]. The liquid obtained from fermented vegetable waste, also known as vege-grout, was discovered to be abundant in nitrogen, carbon, and essential elements such as calcium that are vital for the growth of bacterium. For this reason, using PET plastic as reinforcement with a combination of vegetable grout as a soil binder, especially on weak soil could be an effective soil stabilization method. Therefore, this study was conducted to ascertain the signs of plastic degradation by bacteria from the vegetable grout and unleash the possibilities of vegetable waste and PE plastics of soil stabilization. The combination of PET plastic with natural binder as a soil stabilizer not only will overcome the challenges for civil engineering but also for the solid waste management field.

2. MATERIALS AND METHODS

2.1 Materials

The soil used in this study is the soft soil termed Marine Clay was collected from a coastal area Kukup near a river site, Johor. The soil was classified as SILT of high plasticity which comprises 89.9 % Silt and 10.10 % clay based on the Unified Soil Classification System (USCS) with 22.1 kN/m^3 unit weight and specific gravity of 2.21. The soil in the study area contained a high moisture content of 55.55 %. The engineering properties of the soil are stated in Table 1. The vegetable waste consisted of cabbage, long beans, and cucumbers, with a total weight of 30 kg was prepared. Additionally, 10 g of polyethylene (PE) supermarket bags were included, resulting in a vegetable-to-plastic ratio of 30:0.001 to make vege-grout liquid. The vegetables and the PE bag were collected from the wet markets near Universiti Tenaga Nasional.

Table 1: Basic engineering properties Marine Clay Soil, Kukup Riversite Johor

Soil Properties	Description	Value
Soil type:	Silt (0.002mm<diameter<0.0075mm)(%)	89.90
Silt with high plasicity	Clay (diameter<0.002mm)(%)	10.10
Atterberg Limit	Liquid Limit, LL (%)	54.23
	Plastic Limit, PL (%)	42.90
	Plasticity Index, PI	11.33
	Liquidity Index, LI	2.22
Specific Gravity, Gs		2.21
Moisture Content, w (%)		68.08
In-situ Moisture Content (%)		55.55

2.2 Sample Preparation

The vegetables were first washed and cut before the fermentation process for 30 days to avoid cross-contamination of bacteria from the surroundings. The cut vegetables and supermarket bags were mixed in the container before being properly sealed with plastic wrappers for the fermentation process. The pH of fermented vegetable liquid was taken every week for constant monitoring of pH, temperature, and ammonia levels. After 30 days, the mixture was filtered, and the grout liquid with some plastic residue in a semi-solid state, was then mixed with the soft soil and left for curing to allow the growth of bacteria and degradation of the polymer supermarket bags (Figure 1 (a)). Each curing soil sample consists of different variations of 15 %, 17.5 %, 20 %, and 22.5 % of the stabilization additive liquid grout mixture.

The soil and the mixture of vegetable grout liquid with PE plastic residue (VG-PE) were mixed thoroughly before being poured into the cylindrical PVC pipe mold with a size of 40 x 80 mm. The soil mixture was added in three layers and statically compacted by a tamping rod. The specimen in the mold was left outdoors in an ambient environment for the curing process. The curing process is endured for 14, 21, 28 and 35 days. All the cured samples were prepared and tested in triplicate and the average value were estimated.

Figure 1: Sample preparation involving the (a) fermentation process (b) filtration process of vege-grout containing plastic after the fermentation and the (c) curing process of soil sample containing vege-grout and plastic residue.

2.3 Characterizations

The strength of the soil specimen was tested for mechanical using a consolidated undrained (CU) triaxial compression test according to ASTM D4767-11(2020) using the Digital Tritest 50 press equipped with DS7 ELE software. All specimens before and after curing for 14, 21, 28, and 35 days were consolidated with effective stress of 50, 100, and 200 kPa cell load at the test speed of 1 mm/min. The shear strength parameters, cohesion, and friction angle using effective stress were evaluated. Each curing period sample comprises 15 %, 17.5 %, 20 % and 22.5 % of the stabilization additive liquid grout-PE. Additionally, the California Bearing Ratio (CBR) test was done to determine the deformation behaviour of fermented vegetable wastes containing polymer supermarket bags (PE) liquid grout. Scanning Electron Microscopy (SEM) Model Jeol 6010 and EDX analysis were used to examine the microstructure of the treated soil. All soil samples were coated with platinum coating before observation under SEM.

3. RESULTS AND DISCUSSION

Based on Table 2, the result shows that the pH values of the fermented vegetable waste liquid (vege-grout) increased from pH 4.34 to 6 up to day 21 and remained stagnant at day 35. Mujah et al. [11] highlighted that microbial enzyme activity would be rather active in an alkaline environment ($6.0 < pH < 9.3$). In a previous study by Omar et al. [12], the pH of vegetable grout liquid is around pH 7-8. In this study, a lower pH result might be affected by the existence of plastic waste which contributes to the acidic condition. Nevertheless, the increment in pH results demonstrated the occurrence of enzyme activity of microbes which could induce calcite precipitation in soil. Additionally, the temperature of the vege-grout recorded during the fermentation process was in the range of 23.2 - 24.3°C and none of the ammonia content was detected (Table 2). This indicates that the liquid was safe to be applied in soil. At the end of the fermentation process, some pieces of PE plastics were still observed floating on the surface of the vege-grout liquid without any degradation sign observed.

Table 2: pH, temperature, and ammonia (NH_4) content.

Curing Days	pH	Temperature	Ammonia content
Day 0	4.5	23.6	None
Day 7	4.34	23.5	None
Day 14	4.45	24.2	None
Day 21	5.21	24.3	None
Day 28	6	24	None
Day 35	6	24	None

Figure 2 represents the shear strength behavior of the treated soil within 35 days of curing. All samples were subjected to 50 kPa cell pressure with different concentrations of stabilization additive liquid grout for 14, 21, 28, and 35 curing days. This study only focused on low confining pressure which reflects a better shear strength parameter. All the treated specimens could sustain higher stress as the curing days progressed from day 14 until day 35. Soil treated with 15 % VG-PE possesses a higher strength until day 35 reached 220 kPa at low strain value (2.5 %) as compared to other compositions. Previous findings reported that a 20 % vegetable grout mixture with PET plastic bottle strips, tested at the lowest confining pressure, achieved a maximum strength of only 150 kPa [13]. These results indicate that PET plastic bags are more effective at improving soil strength compared to PET plastic bottle strips. However, the reduction in strength at day 35 treated at higher compositions describes over-consolidated clay which behaves as dense sand. Nevertheless, the material's inelastic behavior ceased towards the end due to strain softening.

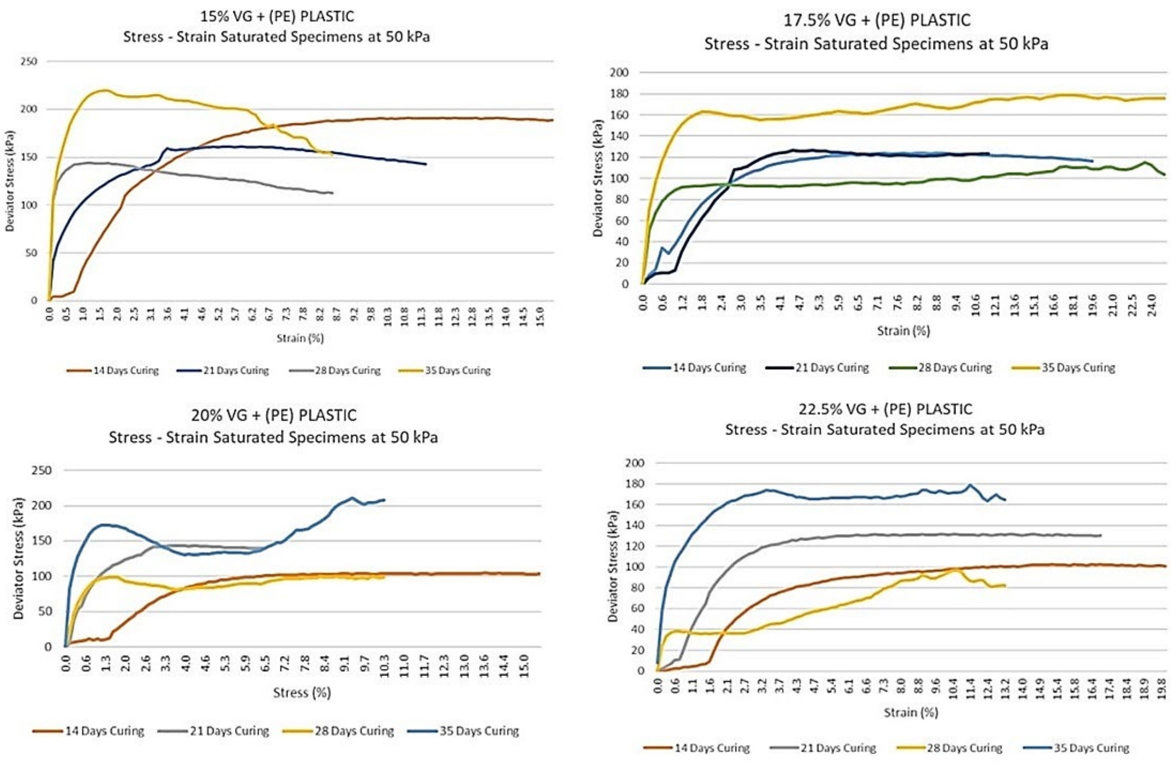

Figure 2: The stress-strain graph for saturated soil containing 15, 17, 20 and 22.5 % vege-grout with PE residue at 50 kPa pressure after 35 days of curing.

These findings can be linked to the characteristics of silt, which turns brittle when dry. Since it exhibits brittle properties, ultimate failure follows shortly after reaching the yield point. It is evident by observing the stress-strain graphs, that the workability of the soft soil may seem disrupted. Furthermore, Ferreira et al. [14] reported that the incorporation of plastic as a fiber reinforcement may potentially enhanced or disrupt the soil strength depending on the interlocking and friction mechanism among soil particles and size of the plastics used. Table 3 reports the computed un-soaked California Bearing Ratio (CBR) results for untreated and treated soil with 15 % of VG-PE mixtures, cured at 35 days. After treatment with 15 % VG-PE mixtures, it was noticed that the value of CBR increased from 0.21 % to 17.1 % and 0.33 % to 27.2 % at 2.5 mm and 5.0 mm penetration respectively. The existence of vegetable grout and PE plastic residue developed friction within the soil particle and demonstrated a similar behaviour as the concrete fiber reinforcement. The inclusion of VG-PE as soil stabilization materials improved the CBR value significantly after curing thus enhancing the deformation behaviour of the soils substantially.

Table 3: Summary of the California Bearing Ratio (CBR) for the untreated and treated sample with 15 % vegetable grout and (PE) plastic

Sample Properties	CBR (Un-soaked) (%) 2.5 mm		CBR (Un-soaked) (%) 5.0 mm	
	Untreated soil	Treated 15 % VG	Untreated soil	Treated
Value	0.21	17.1	0.33	27.2

After 35 days of curing, based on physical observation, a slight change in plastic color has been observed considerably without any degradability changes seen. Although the existence of plastic in soil was able to enhance its strength and durability of soil based on the triaxial test, these findings validate that the likelihood of plastic degradation through the feeding of microbes derived from the fermentation of vegetable waste is notably limited. Zhang et al. [15] also reported the changes in plastic colors after curing but this did not signify the degradation of PE plastic. Among many types of bacteria, *Pseudomonas, Rhodococcus* and *Bacillus* genera are the most frequently reported genera to form biofilms PE plastics. The formation of biofilms will lead to the degradation of PE plastics [6]. Based on the EDS results, the treated soil has higher carbon content, this is due to the presence of carbon from the PE plastic as well. However, the reduction in carbon contents after treatment from 31.22 wt% to 27.25 wt% might indicate degradation of PE plastics after 35 days might occurred. The SEM image in Figure 3 demonstrates the existence of circular-like bacterium which is typically a coccus-shaped bacterium. It was found that this microbe covered most of the soil surface and filled in between the soil grains.

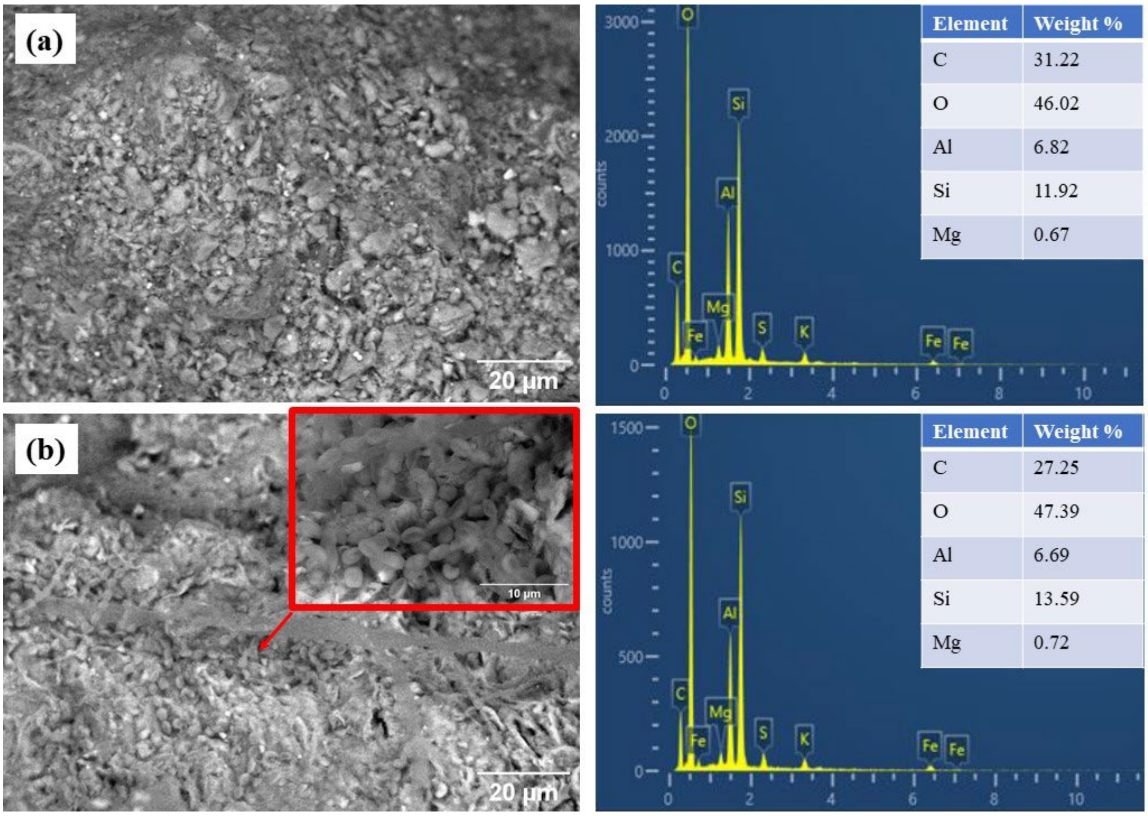

Figure 3: SEM micrographs of soil for (a) untreated and (b) treated with VG-PE after 35 days of curing

In a previous study, microbial analysis of vege grout only proved that the vege grout liquid is free from pathogenic bacteria such as E.Coli and Salmonella [12]. Furthermore, this study represents a significant finding, as the SEM image distinctly reveals the presence of Leuconostoc Mesenteroides. Leuconostoc Mesenteroides, a species of Gram-positive facultative anaerobic bacterium which is frequently found in fermented vegetables. Nevertheless, Ivanov et al. [16] reported that, the existence of this bacterium would also able to act as an agent for the self-healing grout to bind the soil particles. These microbes produce water-insoluble polysaccharides in situ and undergoes bioclogging process which induce aggregation of soil particles and pores clogging. According to Baldovino et al. [17], the presence of calcite from microbes and plastic waste will fill the void in the soil and promote bridges between the soil particles causing consolidation, thus increasing the strength of the treated soil over the curing time. The enhancement in the soil strength of fine-grained soil can be attributed to the formation of calcite due to the presence of ureolytic bacteria [18]. However, it can be seen that there are some parts of the soil uncovered with these bacteria (Figure 3b). The uneven distribution of bacteria may affect the pattern of calcite ($CaCO_3$) precipitation among the soil mixture, thereby influencing the strength of the soil.

4. CONCLUSIONS

In this experimental study, the effects of vege-grout addition on the strength and morphology of the soil were highlighted. The addition of vege-grout was able to enhance the strength of silty clayey soil at 15 % of VG-PE inclusions with the highest strength of 220 kPa. The incorporation of VG-PE in soil stabilization materials led to a significant improvement in the CBR value after curing, thereby substantially enhancing the deformation behavior of the soils. The discoloration of PE plastic and reduction of carbon contents indicates the degradation behaviour. Additionally, the presence of Leuconostoc Mesenteroides in the SEM micrograph represents a significant discovery in this investigation of vege-grout, whereby the function of this bacterium in biocementation of soil has not been previously discovered. Therefore, to gain a more comprehensive understanding of vege-grout technology, in-depth microbial analysis is necessary. It is also recommended to explore different types of plastic content to better understand how this bacterium contributes to plastic waste degradation.

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Author Contributions

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure of Conflict of Interest

The authors declare there are no conflict of interest in this work.

Compliance with Ethical Standards

The work is compliant with ethical standards.

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