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Effects of Biocementation Method on Direct Shear Stress and Unconfined Compressive Stress of Sand

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Abstract

Objectives: To explore bio-mediated method to strengthening soil engineering parameters. **Methods:** Besides, issues such as environmental pollutions engineers invent new methods for improving mechanical soil properties. During the last decade bacteria cultivation technique has become one of the innovative methods which are more capable compared with other methods. **Results:** The new method named Microbial Induced Calcite Precipitation (MICP) provides a suitable condition in order to derive calcite between sand particles by adding cultivated bacteria and cementation solution to it. In fact, reaction between these solutions creates strong bonds which lead to strengthening physical properties of sand. **Conclusion:** The direct shear test and unconfined compression test results demonstrate non-homogeneity distribution of solutions in the sand samples.

Keywords: Bio-Grout, Direct Shear Test, MICP, Sand Gradation, Unconfined Compression Test

1. Introduction

The environmental issues such as global warming and sustainable development motivated the researchers to change the old methods with new ones. A novel method has been recently suggested by researchers in order to improve mechanical properties of soil. This method is inspired from formation of sandstone in the nature. The calcite precipitation between soil particle is the main reason of cementation which caused by bacteria existence in the soil. Besides, the cementation solution in the nature can activate the bacteria and change the situation to better condition for microorganisms. A sustainable technique can be simulated in soil by adding bacteria and cementation solution which termed as microbially induced calcite precipitation (MICP). Bio-mediated leads to strengthening soil engineering parameters. The other significant application of this method is improving the strength[1,2] and durability[3,4] of concrete, and brick[5]. The whole process based on urea hydrolysis which defined as a chemical process that the urease enzyme breaks down urea ($CO(NH_2)_2$). The main source of the enzyme can be either supplied externally[6] or in situ by urease-producing microorganism[7-9]. The whole process happens in following sequences:

First, 1 mol of the urea is decomposed to 2mol of ammonium with presence of urease.

$$CO(NH_2)_2 + 2H_2O \rightarrow 2NH_4^+ + CO_3^{2-}$$

Second, an ideal environment for calcite precipitation is provided by increasing pH with ammonium (NH_4^+) presence. Finally, the calcium ion (Ca^{2+}), supplied by calcium chloride, reacts with carbonate ion (CO_3^{2-}) and leads to calcite precipitation.

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow$$

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In[10] studied the ability of heal degraded calcite bonds post-shearing that evaluated using monotonic undrained shearing and dynamic centrifuge tests, and comparing the sand behavior before and after the healing process. The results showed that MICP-treated sands can be healed to restore initial cementation conditions after monotonic or dynamic shearing has degraded the cementation level by re-injecting additional cementation media and using active existing bacteria[11]. In examined the influence of surfactants on the transportation and delivery of the bacteria as well as on MICP performance and distribution. They gained that surfactant (Tween 80), by making adsorbed to the clay, as well as to the bacterial cells, prevents bacteria from being rapidly encapsulated by calcite crystals, on the other hand by adding surfactant, less than 2% of the bacterial cells were retained in sand columns when surfactant was used while 15% was retained under no use of the surfactant[12]. In took a triaxial shear analysis to estimate the stiffness and shear strength of MICP employed sands with cementation levels ranging from young, uncommented sand to an extremely cemented sandstone-like state, and different stress paths caused variations of the shear strength and volumetric behavior. The results demonstrated that the peak stress ratio (q/p’) increased from the loose untreated sand value of 1.3 up to 1.9 for cemented sand with a shear wave velocity of 1,400 m/s[13,14].

2. Material and Method

2.1 Sand Properties and Molds

To evaluate the potential of MICP method on Sand and determining the effects of MICP on sand several cubic and cWylindrical molds were prepared. After filling up the molds with similar conditions, the injection of solution has been done for them in series. Finally, direct shear test and unconfined compression test were conducted on the prepared samples. The cubic molds were made out of galvanized steel sheets with standard dimensions of direct shear test (60x60x20 mm). Also, the cylindrical molds made out of PVC with dimensions of 35 mm diameter and 70 mm height. After filling up the molds, all samples compacted to dense condition with dry density of 1800 kg/m^3. Table 1 presents the specification of sand. The samples were named with respect to their grain size. Also, Gradation curve is shown in Figure1. It is obvious that all samples have a uniform gradation.

Table 1. Samples specification and name

Label of samples		Average grain size	Samples
Untreated	Treated		
UnT14	T14	2.3 mm	14
UnT30	T30	0.7 mm	30
UnT50	T50	0.4 mm	50
UnT80	T80	0.2 mm	80

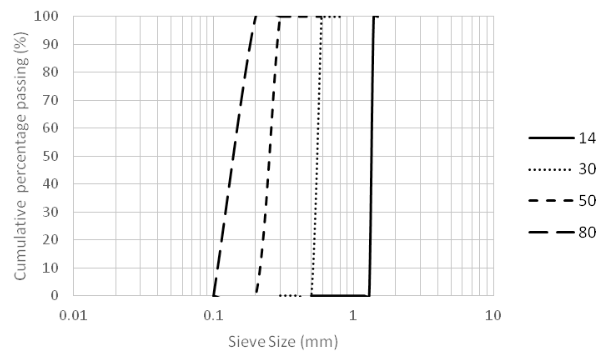

Figure 1. Gradation curve of samples.

2.2 Bacteria cultivation and cementation solution

Like the previous studies, Sporosarcina pasteurii is determined as aerobic bacteria for cultivation. The process of cultivation is determined as mentioned:

- Solution containing 15 gr/lit of yeast extract was prepared as medium with distilled water.
- By adding 10 gr/lit of ammonium chloride (NH_4Cl) and 0.024gr/lit of nickel chloride ($NiCl_2$) to medium prepared for bacteria cultivation, the solution was ready to be cultivated with pH 8.5.
- After adding bacteria to medium, the whole solution placed in incubator with temperature of 25°C for 24 hours.
- Finally, the bacteria activity was measured in order to ensure the process accuracy.

The cementation solution was prepared with 1mol of urea and 1mol of calcium chloride solution. All the cementation solution materials were dissolved in distilled water. Figure 2 shows the bacteria and cementation solution prepared for bio cementation process. The bacteria solution and cementation solution was injected to samples with a **Peristaltic Pump** in order to have a stable and accurate injection pressure and constant flow rate. Figure 3 shows the pump used to injecting the solution in the samples.

Figure 2. Preparation of bacteria solution.

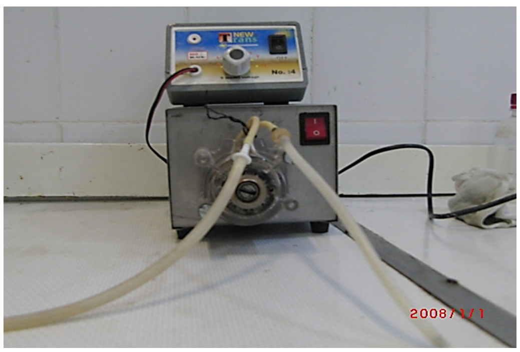

Figure 3. Pump used for injection of solutions.

2.3 Direct shear test apparatus and unconfined compression test apparatus

The direct shear test was conducted with Ingrates direct shear test apparatus. Tests were performed with strain control condition with the speed of 0.6mm/min with 55, 111 and 222kPa normal stress. Tests were stopped after reaching 10% of strain. The unconfined compression test was carried out with AZ moon apparatus. Loading rate was 1mm/min and tests were continued until the samples reaching the failure condition. Figure 4 shows the apparatus used in this study.

Figure 4. Direct shear apparatus and unconfined compression test apparatus.

3. Results and Discussion

Normalized shear test stress-horizontal displacement diagram was obtained from direct shear test. Figure 5 shows the direct shear test results for treated sand. As it is shown in the Figure 5, peak shear stress of samples was increased after treatment due to cementation. The peak state of shear strength shows the cemented behavior of binding between particles. Also, the ultimate shear strength of samples are reaches to constant value equal to untreated samples which can be one of the bio cemented sand specification. The reason of constant ultimate shear strength is related to characteristics of the cementation process on the sand particle which is happened after bond breakage between them. Indeed, after breaking the bonds between particle, sand grains change to initial untreated condition. However, a steep declining can be seen after the peak state which can be related to the brittle characteristic of the cemented bonds between particles. Also, this characteristic can be one of the specifications of bio cemented sand. The other notable case happened at the difference between peak shear stress and ultimate shear stress of samples with 55 kPa normal stress. As it is shown in Figure 5, the best treated condition happened in sample with 55 kPa normal stress. This can be related to limited range of the normal stress which can be inserted to cemented sand. For samples with high normal stress 222 kPa, bonds between particles collapse after loading. Hence, the difference between peak shear stress and ultimate shear stress of sample with 222 kPa normal stress is less than sample with 55 kPa normal stress. Besides, the high normal stress can lead to a higher shear stress which can be seen in Figure 5. The cylindrical samples were tested for unconfined compression test. Figure 6 shows compressive stress-axial strain diagram of bio treated sand. As it is shown in Figure 6, the compressive stress is increased by decreasing the sand grain size. This process can be seen in direct shear test results, too. According to unconfined compression test procedure, most of the cylindrical samples fail. Table 2 shows comparison between the maximum shear the stress of close shear analysis outcomes and free compression analysis effects. There is a first correlation between the sequence of the direct shear analysis and free compression analysis. It can be concluded that by decreasing the grain size of samples, both shear stress and compressive stress are increased. Figure 7 demonstrates the peak state of shear stress and compressive stress of samples. It is obvious that both of them have an inclining steep which is related to gradation.

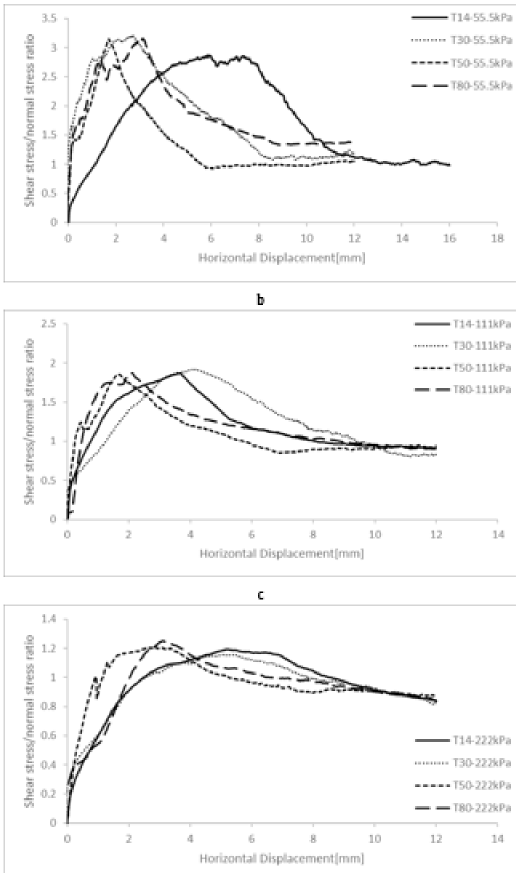

Figure 5. Normalized shear test stress-horizontal displacement diagram with
(a) 55 kPa (b) 111 kPa (c) 222 kPa normal stress.

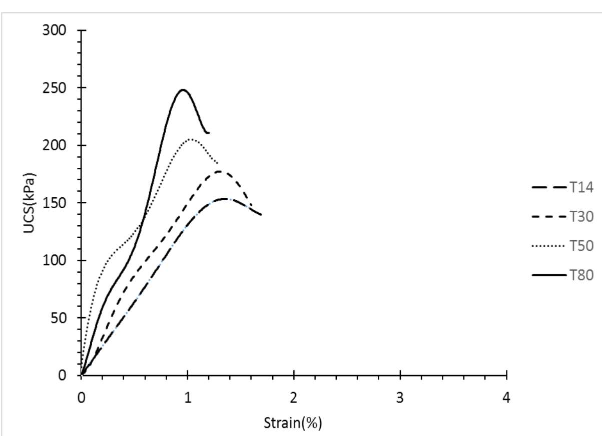

Figure 6. Unconfined compression test results.

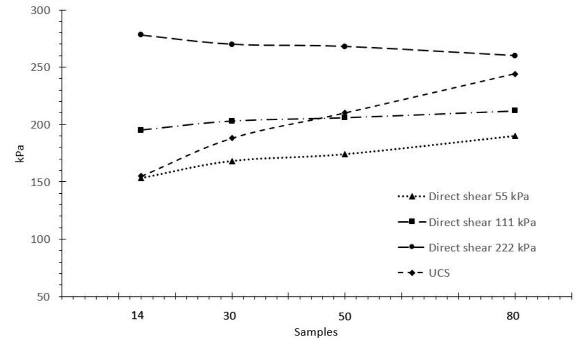

Figure 7. Peak state of shear stress and compressive stress of samples.

Table 2. Maximum shear stress of direct shear test results and unconfined compression test results

Sample	Direct Shear			UCS
	55 kPa	111 kPa	222 kPa	
T14	153	195	278	155
T30	168	203	270	188
T50	174	206	268	210
T80	190	212	260	244

4. Conclusion

- By decreasing the particle size, the shear strength of employed unit is extended which indicates that there is an opposite relation between particle quantity and sand advancing the rate of employed sand.
- The final shear strength of employed and untreated units reaches to almost the same amount. It is obvious that the bio cementation process does not have any effects on the initial characteristics of sand
- Unconfined compression test results show that bio cementation process has the principal effect on bonding.
- According to samples breakage pattern, non-homogeneity of the bacteria and cementation solution distribution is the main reason of collapse in unconfined compressive test.

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