Research on the Effect of Urease on the Energy Absorption in Shanghai Clay by Unconfined Compressive Test

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Abstract. Urease was attempted to improve the quality of soil as a novel material rising in recent years. The unconfined compressive tests (UCT) have been carried out on soils mixed with urease at a series of concentration. The unconfined compressive strength (UCS), energy absorption (E_i), cumulative energy absorption (E_{i,total}) of 4 types of samples was also analyzed to evaluate the effect of reinforcement. Results from tests show that a certain concentration of urease has a positive effect on UCS and E_i of the clay, and it appeared best with the concentration of 3g/L. Urease of 4g/L achieved the maximum value in energy absorption within certain strain range. Conclusion is differed for E_{i,total} as the values of samples mixed with urease are all decreased compared to control sample. It is important for civil engineers to understand the stabilizing mechanism of urease for design and construction of civil engineering project.

1. Introduction
Shanghai clayey soil is a soil with small sand content, relatively small particle size, low permeability, high plasticity, large specific water content and porosity ratio, high compressibility, low strength, and easy deformation [1]. Due to the micro-structural characteristics of pores and structural morphology of Shanghai clayey soil, there are a series of unfavorable engineering characteristics, among which high compressibility and low strength are the most prominent quality problems in engineering construction [2]. In short, Shanghai clayey soil generally cannot meet the needs of engineering construction before processing. Over past several thousands of years, many materials had been used to mix with soils to strengthen its behavior. However, enzymes used as additives in soil reinforcement have only gradually become popular in recent years and as a kind of enzyme which proved to be work for soil reinforcement urease is rarely studied by civil engineers. Searches about enzyme are as follows: Comparison of the efficiency of different urease inhibitors and their effects on soil prokaryotic community in a short-term incubation experiment found that urease inhibitors, especially NBPT, enriched ureolysis groups [3]; Research on persistence of immobilised and total urease and phosphatase activities in a soil amended with organic wastes indicates that the effect of organic amendment on immobilised phosphatase activity was similar to that shown by immobilised urease but less pronounced [4]; Study on durability of enzyme stabilized expansive soil in road pavements suggested that strength of stabilized soils was considerably increased with the addition of enzyme based stabilizer, revealing its ability to maintain the material stiffness over moisture fluctuation [5]. Other studies have also shown that certain enzymes have positive effect on soil reinforcement [6-16]. Thus, research on the application of enzyme in soil is meaningful and necessary.
Urease is an environment-friendly material as an enzyme native to plants that produces carbon dioxide and ammonia in a reaction that catalyzes the hydrolysis of urea [17]. It is abundant in soybeans and beans according to the paper. Three possibilities exist to explain the effect of enzymes on the engineering properties of soils [17]: Enzymes influence the bonds between soil particles through a series of chemical reactions; Enzymes improve some soil engineering and erosion properties through a set of biological activities within the soil body; A combination of chemical reactions and biological activities leads to the change in some engineering properties of enzyme-treated soil samples.

The unconfined compressive strength (UCS) of the soil mixed materials are essential parameters in the design and construction of many civil engineering projects, such as excavation engineering etc. What’s more, energy absorption ($E_i$) is an index used by author to evaluate the compressive strength of soil in a different way in which can dig more valuable information about the characteristics of reinforced soil according to the test results. The energy absorption should be the integral of the force over displacement in theory, but due to the data obtained are scattered and not continuous, the trapezoidal area under the stress-strain curve is used instead since the strain is small for which author believes the substitution is reasonable. It was calculated by the strain-stress curve according to the formulas listed in chapter 2.

Urease have been recently used various applications due to their availability, justified costs and environment-friendly. However, there is very limited information available on the strength of soil stabilized by urease. Therefore, the purpose of this work is to investigate the effects of urease on the strength characteristics of soil samples. The data obtained from the study are expected to provide fundamental basis for construction and design in civil engineering.

2. Materials and Methods

2.1. Materials

The soil used in this study is a typical Shanghai clayey soil, which is taken from a construction site in south campus of University of Shanghai for Science and Technology. The physical and water-physical properties of the soil are shown in table 1. The particle size distribution curve of Shanghai clayey soil used in this test is shown in figure 1.

The urease used in test is commercially obtained and in powder form. Table 2 shows the physical and chemical properties of urease.

| Liquid limit/% | Plastic limit/% | Plastic index | Optimum water content | Max. dry density (g·cm$^{-3}$) | Relative density of soil |
|---------------|----------------|---------------|------------------------|-------------------------------|-------------------------|
| 42.34         | 20.56          | 21.78         | 20.72                  | 1.62                          | 2.73                    |

| Content (%) | Density (g·cm$^{-3}$) | Molecular formula | Molecular mass |
|-------------|-----------------------|-------------------|----------------|
| 98          | 1.6±0.1               | C$_2$H$_6$         | 60.055         |
Figure 1. Particle size distribution of Shanghai clayey (analyzed by Laser Particle Sizer from Malvern Instruments Ltd. Shanghai).

2.2. Sample Preparation
The mixing of soil and each type of admixture in the laboratory were all performed using a mortar mixer. The sample preparation method and the method for unconfined compressive test (UCT) is similar to the procedures recommended in many reference guides [18]. Test arrangement of soil samples are shown in table 3. It should be noted that the urease powder is first dissolved in water to make a solution with certain concentration, and then mixed with the soil.

Table 3. Test arrangement of soil samples.

| Type | sample     | Concentration of urease (g/L) | Water content (%) | Sample size |
|------|------------|-------------------------------|-------------------|-------------|
| No.1 | Soil       | 0                             | 18                | 5           |
| No.2 | Soil-urease| 2                             | 18                | 5           |
| No.3 | Soil-urease| 3                             | 18                | 5           |
| No.4 | Soil-urease| 4                             | 18                | 5           |

Figure 2. Test scheme in the study.

2.3. Experimental Program and Formulas
Figure 2 shows the test scheme in the study. The data was recorded for every 0.2 mm drop of sample
(0.25% strain), and experiment would stop only when 5 groups of data were obtained after the stress starts to decrease. The equations used in the study are as follows:

\[ \Delta \varepsilon_i = \varepsilon_{i+1} - \varepsilon_i \]  
\[ A = \frac{1}{4} \pi d^2 \]  
\[ A_a = \frac{A}{(1 - 0.01 \varepsilon_i)} \]  
\[ E^i = \frac{(\sigma_i^+ + \sigma_i^-) \times \Delta \varepsilon_i}{2 \times h \times A_a} \times \frac{h}{1000} \]  
\[ E_{total}^i = \sum_{k=1}^{i} E^k \quad (k = 1, 2, 3 \ldots) \]

where \( \varepsilon_i \) and \( \sigma_i \) is the strain and stress of i-th data; \( A \) and \( A_a \) are the initial area and correction area of sample; \( E^i \) and \( E_{total}^i \) are energy absorbed in phase i and total energy absorbed before phase i (include phase i); \( h \) and \( d \) is the height and diameter of sample. It should be noted that for all samples, \( h \) is 80 mm and \( d \) is 39.1 mm.

3. Results and Discussions

3.1. Unconfined Compressive Strength (UCS)

Figure 3 shows the relationship between stress and strain of 4 different reinforced conditions for No.1-4 types of soil. The maximum stress and corresponding strain are marked in the figure. It can be seen from figure 3, for sample reinforced with urease, sample mixed with 3 g/L urease (No.3 sample) has the highest unconfined compressive strength (121 kPa) while the sample with 2 g/L urease (No.2 sample) has the lowest unconfined compressive strength (101 kPa). Their difference is approximately 20 kPa. What’s more, the value of No.1 and 4 is in between. And the UCS of No.3 sample increased by 12% compared to that of control sample (No.1 sample). It indicates that a certain concentration of urease can indeed increase the UCS of the soil and there exists an optimal incorporation concentration in terms of increasing the UCS. The concentration of 3 g/L is the best for UCS in terms of the paper scope. Due to the limited information available from the stress-strain diagram, it is significantly to analyze the reinforcement effect of urease from the perspective of energy absorption.

Figure 3. Stress-strain relationship of samples.  
Figure 4. Relationships between \( E_i \) and \( \varepsilon \).
3.2. Energy Absorption

Figure 4 shows the relationship between energy absorption and strain. Figure 4 is similar to figure 3 from the trend of change, but details are various in many aspects. Data annotation in figures 3 and 4 revealed that the strains are different when the ordinate value reaches the peak for each sample (for example, No.1 sample gained the UCS of 108 kPa when strain is 2.5% but achieved the energy absorption of 2609 when strain is 2.75%) which suggested that it is too monotonous to evaluate the reinforcement effect of urease only from the maximum UCS. The rules of reinforced effect of urease concentration applied well as the sample mixed with 3 g/L urease (No.3 sample) has the highest energy absorption (2894 J) and the sample with 2 g/L urease (2393 J) has the lowest energy absorption. However, it should be noted that No.4 sample possesses the strongest energy absorption capacity (2583 J at 1.75% strain, where the values are 2154, 1137 and 1304, respectively) before reaching the peak. Conclusion could be drawn that soils can greatly improve the compressive capacity within a certain range of deformation after 4 g/L urease has been added in. Well understanding and mastering the rule is of great significance for applications which are strict with the deformation in civil engineering. Similarly, there is an optimum concentration of urease for enhancing the energy absorption capacity of the soil which equals an increase in soil strength within a small strain range and it is 4 g/L in term of the paper scope. More studies are needed to reveal the most suitable concentration of urease and regularity of urease to strengthen soil.

3.3. Cumulative Energy Absorption

Figure 5 shows the relationships between cumulative energy absorption ($E_{i \text{total}}$) and strain ($\varepsilon$), figure 6 are the bar graph of final cumulative energy absorption for 4 types of soil. Pattern is the same as that of energy absorption ($E_i$) as figure 5 suggested that samples mixed with 4 g/L urease have the maximum value (20348 J) before the strain reaches 2.75% and samples mixed with 2 g/L have the minimum value (11589 J), the difference of them are 8759 J and the value of No.4 sample increased by 16.9% compared to the control sample. But rule is differed when the whole process was taken into account, as shown in figure 6 the No.1 sample (with no urease) possesses the highest cumulative energy absorption in the end (27148 J) which is inconsistent with the conclusion that sample has the maximum UCS when mixed with 3 g/L urease. The values of final energy absorption for samples mixed with different concentration of urease are 18713, 25342 and 20348 J, respectively. Final $E_{i \text{total}}$ of No.2-4 decreased by 31%, 6.7% and 25% respectively compared to that of No.1 sample. This may be interpreted as the urease has obviously effect on strength of soil within initial deformation stage while the later trend is implicit due to the limited data.

Further study is urgently needed to reveal the principles of urease in strengthening the engineering properties of soils. This finding is of great significance to the short-term and long-term arrangements of construction in civil engineering.
4. Conclusion
In this study, the unconfined compressive tests were carried out on soil mixed with different concentration of urease. Unconfined compressive strength and energy absorption have been used to evaluate the reinforcement effect of soil in various aspects. The main conclusions were drawn as follows:

1) Urease can increase the unconfined compressive strength of Shanghai clay to a certain extent, and within the scope of this study, the result is most significant at a concentration of 3 g/L.

2) Results for energy absorption are similar to the unconfined compressive strength in terms of change trend but differed in some details. Urease of 3 g/L possessed the best effect of improving throughout the whole test and urease of 4 g/L achieved the maximum value in energy absorption within certain strain range.

3) Samples mixed with urease have lower final energy absorption than control sample which means that it is advisable to increase the compressive strength of the soil with urease in the short term.

Although there have been many researches on effect of cement, fly ash on mechanical properties of soil, few researches were focused on effect of urease on soil properties. Thus, this research appears to be more important. Well understanding the difference in improving mechanism of urease on soil properties with is of huge significance not only in the design, construction, support, protection and maintenance of many related engineering projects, but also in environmental protection and sustainable development.

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