Fixation of Optimum Condition for Enzyme-Induced Carbonate (EICP) Precipitation as a Soil Improvement Technique

Keywords: EICP, soil improvement, optimum condition

Ehime University
G. B. S. Pratama, H. Yasuhara, N. Kinoshita

Introduction

The application of calcite precipitation method by urease enzyme induction as a potential soil improvement technique has been confirmed. It can significantly improve the strength of the soil (Neupane *et al.*, 2013) and reduce the permeability and porosity of soil (Yasuhara *et al.*, 2012; Neupane *et al.*, 2013). Understanding of appropriate procedure of this method is considered essential to approach the optimum condition of soil improvement. In this work, a new preparation technique, which is urease concentration measurement, was presented as the aim to make referenceable conditions. The urease activity of urease enzyme was estimated by the conductivity method. The effect of factors such as the concentration of urease, the curing time, and the preparation of soil specimens on the process of enhancement of treated soil was also examined in this work.

Methods

Each urease enzyme has its own urease activity (i.e., the ability of an enzyme to hydrolyze urea into ammonia). In this case, the urease activity of two products of urease enzyme obtained form two different companies (Kishida and Junsei) was estimated by the conductivity method. The experimental procedures developed by Whiffin V.S. (2004) were adopted. The evolution of conductivity with time after mixing 15g/L urease solution and 1g/L urea solution in 50mL total volume was measured using LCR meter. A standard curve was provided by determining the conductivity resulting from the complete hydrolysis of several concentrations of urea. The urease activity was determined by calculating the gradient of the conductivity changes versus time, which is expressed in Equation (1).

$$\text{Urease activity (U/g)} = \frac{\theta_{ms}}{\theta_{sc}} \times v \times N \qquad (1)$$

θ_{ms} is the gradient of conductance changes, θ_{sc} is the gradient of the standard curve, v is the volume of sample (L), and N is the final concentration of ammonia (mMol/L).

Precipitation of calcite was evaluated directly in transparent test tubes. The total concentration of Urea-$CaCl_2$ was fixed at 0.5 and 1 mol/L. Test tube experiments were conducted to evaluate the effect of urease enzyme concentration and the curing time on the precipitated amount of $CaCO_3$. The urease concentration varied from 2-12 kU/L.

The PVC cylinder tests (50mm in diameter and 100mm in height) were used to evaluate the effect of the preparation sample method on the UCS strength of treated soils. There are two different conditions conducted for preparing the samples, which are filtered and non-filtered urease enzyme and various temperature treatment.

Results

The conductance changes by time are depicted in Fig 1. In order to determine urease activity of urease enzyme, a standard curve was provided and depicted in Fig 2. The gradient of conductance changes in Fig. 2 seems straight enough with R^2 close to 1, both urease enzyme from Kishida and Junsei company. By using Equation (1), urease activity of the enzyme by Kishida and Junsei company are estimated at 2346 and 3608U/g, respectively. Urease by Junsei company will be utilized to the next step due to higher result and the amount of its urease activity will be used to measure urease concentration in the test tube experiment.

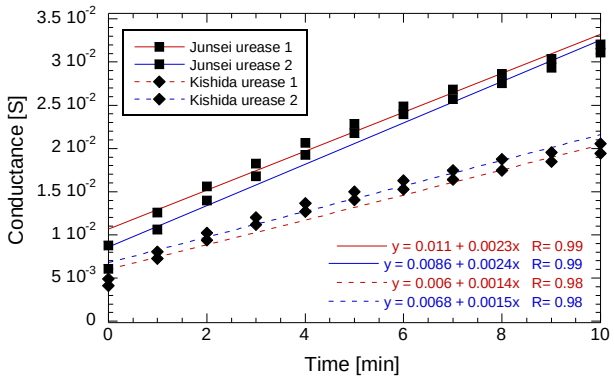

Fig 1. Evolution of the conductivity with time

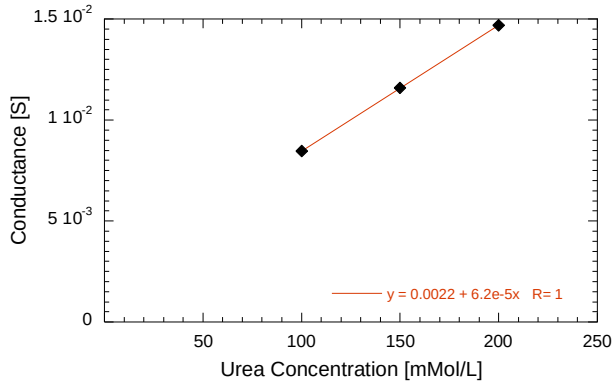

Fig 2. Standard curve of complete hydrolysis of urea

The evolution of precipitation ratio as the effect of urease concentration is depicted in Fig 3. After 3 days of curing time, the result shows that the precipitation ratio increases gradually with increasing urease concentration. For 0.5 mol/L reagent concentration (Urea-$CaCl_2$), Precipitation ratio approaches 100% at 12kU/L urease concentration. In contrast, precipitation ratio of 1.0 mol/L reagent concentration also increases with increasing urease concentration, but haven't reached 100% precipitation ratio yet. The precipitation ratio approaches maximum at 53.8%. The urease concentration was selected at 6 and 8kU/L for the next step. The evolution of precipitation ratio with curing time is depicted in Fig. 4.

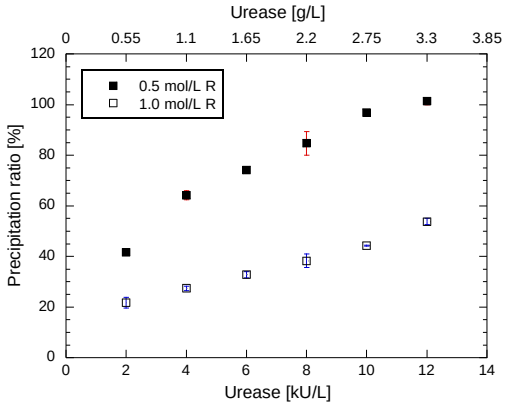

Fig. 3 Evolution of precipitation ratio at various urease concentration

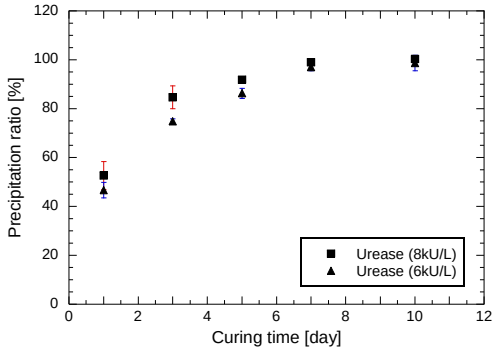

Fig. 4 Evolution of precipitation ratio with curing time

Fig. 4 shows that using 6kU/L urease concentration approaches 100% precipitation ratio at 10 days curing time while 8kU/L urease concentration need 3 days faster. However, precipitation ratio at 7 days curing time shows close results for both 6 and 8kU/L urease concentrations. For the economic reason, 6kU/L urease concentration with 7 days curing time was used to prepare a sample for UCS tests

UCS test results of two different conditions of the soil sample are shown in Fig. 5. The first condition is making grout solution with filtered and non-filtered urease solution and the second condition is making 3 different treatment temperatures (non-oven, 30˚C, and 60˚C). In this experiment, soil samples were dried in 24h oven after cured for 7 days, except for non-oven samples.

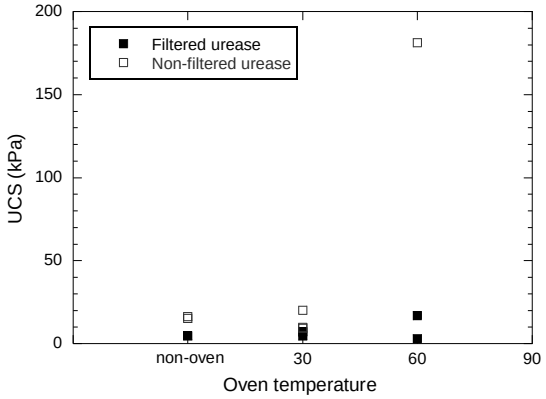

Fig. 5 UCS test result at various condition of sample

The result shows that the samples with non-filtered urease have higher UCS strength than the samples with filtered urease. It may be because the samples with non-filtered urease use all urease content, while the samples with filtered urease might not really use all urease content due to the filtering process. On the other hand, oven temperature brings significant effect to UCS strength, especially for the samples with non-filtered urease. The UCS strength increased as the oven temperature was raised. In contrast, the oven condition didn't affect the samples with filtered urease. The strength of the samples is relatively the same in all oven conditions. This result reveals that while using a sample with a dissolved particle, it can bring higher UCS strength when the sample is heated.

Conclusion

The optimum condition of enzyme induced carbonate precipitation as soil improvement was evaluated. The fixed condition to reach an optimum result is using 6kU/L urease and 0.5 mol/L reagent (Urea-$CaCl_s$) concentration. This combination could approach 100% precipitation ratio at 7 days curing time. The optimum condition for UCS sample preparation is using a non-filtered urease solution and the sample dried in 24h oven with high temperature after the curing process.

References

Neupane, D. *et al.* (2013) 'Applicability of enzymatic calcium carbonate precipitation as a soil-strengthening technique', *Journal of Geotechnical and Geoenvironmental Engineering*, 139(12), pp. 2201–2211. doi: 10.1061/(ASCE)GT.1943-5606.0000959.

Yasuhara, H. *et al.* (2012) 'Experiments and predictions of physical properties of sand cemented by enzymatically-induced carbonate precipitation', *Soils and Foundations*. Elsevier, 52(3), pp. 539–549. doi: 10.1016/j.sandf.2012.05.011.

Whiffin V.S. 2004. 'Microbial CaCO 3 Precipitation for the production of Biocement', Murdoch University.