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Utilization of soybean powder as the additional material on calcite precipitation method for improving the strength of liquefiable soil

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Abstract. This research was carried out to evaluate the addition of soybean in the calcite precipitation method as a soil improvement technique. The evaluated soil was poorly graded and liquefiable sand with a specific gravity of 2.69. The precipitation test was performed to obtain the optimum concentration of grouting solution. Various combinations of soybean and reagent composed of urea and calcium chloride were prepared and were applied to sandy soil through the percolation method. The impacts of soybean on improving the shear strength of treated soil were examined using unconfined compression tests. The result of this study shows that the use of soybean shows a significant enhancement of the soil strength. The strength of 168 kPa was achieved when 60 g/L of soybean added to the grouting solution, which is also promoted a calcite amount of 3% of the soil mass. This research elucidated that the addition of soybean in the calcite precipitation technique is possible to optimize the calcite precipitation method's applicability as the soil improvement technique.

1. Introduction

Soil liquefaction is a process that transforms the saturated sandy soil into a cohesionless form due to the repeated shaking caused by the waves of the earthquake [1]. Liquefaction happens in areas vulnerable to big earthquakes made from saturated sand deposits with low density when co-seismic surface movements are larger than the threshold value [2]. It promotes the decreasing of the soil's bearing capacity and thus can cause massive damage and casualties. Hence, the method for improving the strength of liquefiable soil needs to be developed.

Many technique have been presented for their possible applications to mitigate the liquefiable soil, such as the application of recyclable materials [3–6], passive site remediation [7–9], induced partial saturation [10], and bio-chemical grouting [11,12]. Bio-chemical grouting is considered as a promising method to increase the strength of liquefiable soil. Shear strength varying from 1 to 12 MPa was achieved in 100 m^3 soil experiments [11,12]. However, there are some unresolved issues concerning the use of bacterial cells in the bio-chemical grouting method [13–16]. Microbial processes are complex; hence it is challenging to apply the method on a commercial scale [13]. In addition, reagents with high concentrations also inhibit bacterial growth [14]; thus, bacterial activity in the soil is ineffective [15,16].

Recently, an alternative method using the urease enzyme was also introduced. Purified jack bean urease is used instead of the bacterial cell [17,18]. This method can improve the unconfined compressive strength of treated sand up to 1.6 MPa [18,19]. The urease enzyme is utilized to convert urea into ammonium ions (NH_4^+) and carbonate ions (CO_3^{2-}). Thus, CO_3^{2-} react with Ca^{2+} to produce calcium carbonate crystal [20]. The detailed chemical reactions during the calcination process are shown in equations (1) - (3). The grouting solution, made of calcium chloride, urea, and urease, is injected into the soil. The precipitated calcite can form bonds between sand grains, thus increase the cohesion of treated sand [21]. The expected improvement in this method is illustrated in Figure 1.

$$CO(NH_2)_2 + 2H_2O \xrightarrow{urease} 2NH_4^+ + CO_3^{2-} \quad (1)$$

$$CaCl_2 \rightarrow Ca^{2+} + 2Cl^- \quad (2)$$

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3 \downarrow (precipitated) \quad (3)$$

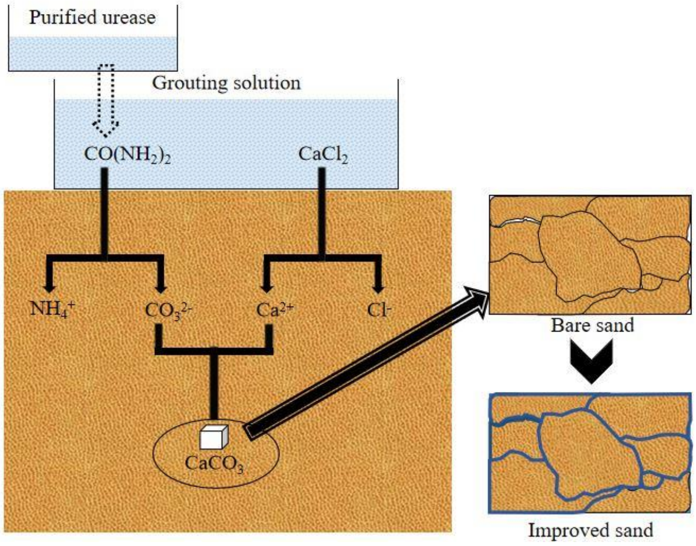

Figure 1. Calcite precipitation process [19]

Putra et al. [22] reported that the urease enzyme's use has an essential issue in its cost. The urease enzyme of jack bean meal was promoted from high purity process; thus, it may be very costly, especially for the real scale application [22]. Hence, the alternative materials should be essentially considered to replace or substitute the urease enzyme. Several studies have been conducted to evaluate different materials as a potential source of urease enzymes, such as cabbage [23], watermelon [24], jack bean [25], and soybean [23,26,27]. The utilization of soybean crude urease, which is obtained by mixing soybean powder and water, is good enough to be used for soil treatment [23,26,27]. Calcite precipitation treatment using soybean crude urease was reported to increase soil strength 1.5 times greater than soil without treatment [26]. The deviator strength improvement of treated soil using calcite precipitation with soybean crude urease through the vacuum pump is varied between 30 kPa to 170 kPa [27]. However, further research is needed to examine soybean effects in a more practical method. Hence, in this research, the effect of adding soybean to calcite precipitation technique and its impact on soil strength of the treated liquefiable soil is examined.

2. Materials and Methods

2.1. Materials

The grouting solution used in this study consist of high purity $CaCl_2$, urea, urease enzyme, and soybean powder. $CaCl_2$ and $CO(NH_2)_2$ with purity more than 95% were acquired from Kanto Chemicals Co., Inc., Tokyo, Japan. The purified enzyme urease of jack bean was produced by Kishida Chemical Co., Inc., Japan, while the powdered soybean with purity more than 95% was obtained from Gasol Pertanian Organik Co., Inc., Indonesia. The soil evaluated in this study is poorly graded liquefiable sand with a coefficient of uniformity (CU) of 4.67 and specific gravity (Gs) of 2.69. The curve of the grain size distribution of liquefiable sand is shown in Figure 2.

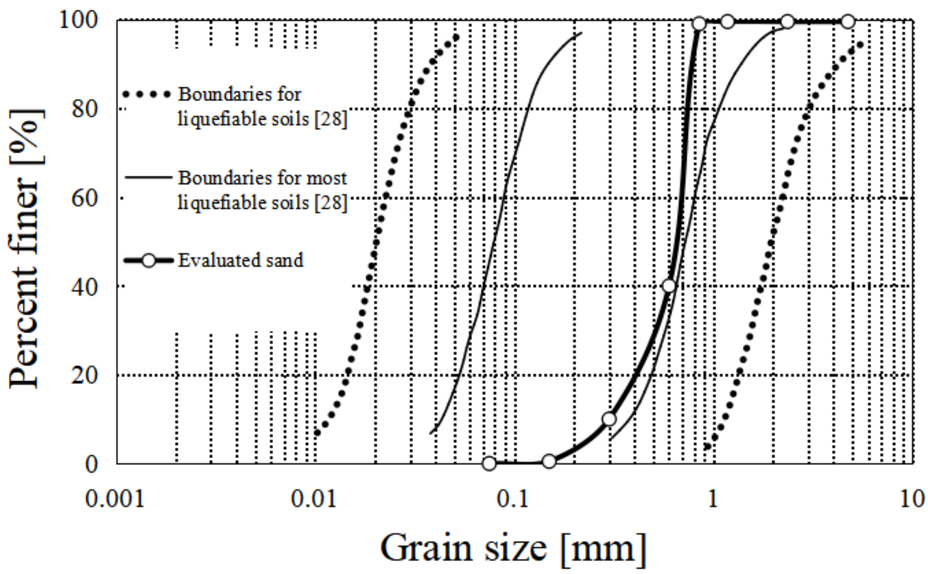

Figure 2. The grain size distribution of evaluated sand

2.2. Precipitation Test

Precipitation tests were carried out to determine the amount of calcite mass formed by each combination of grouting solution without additives. The grouting solution was prepared by mixing reagent and urease solution with distilled water separately and mixed thoroughly to make a volume of 12 mL grouting solution. The solution was then put into a settling test tube and left at room temperature for three days of curing time. The experimental procedures are illustrated in Figure 3.

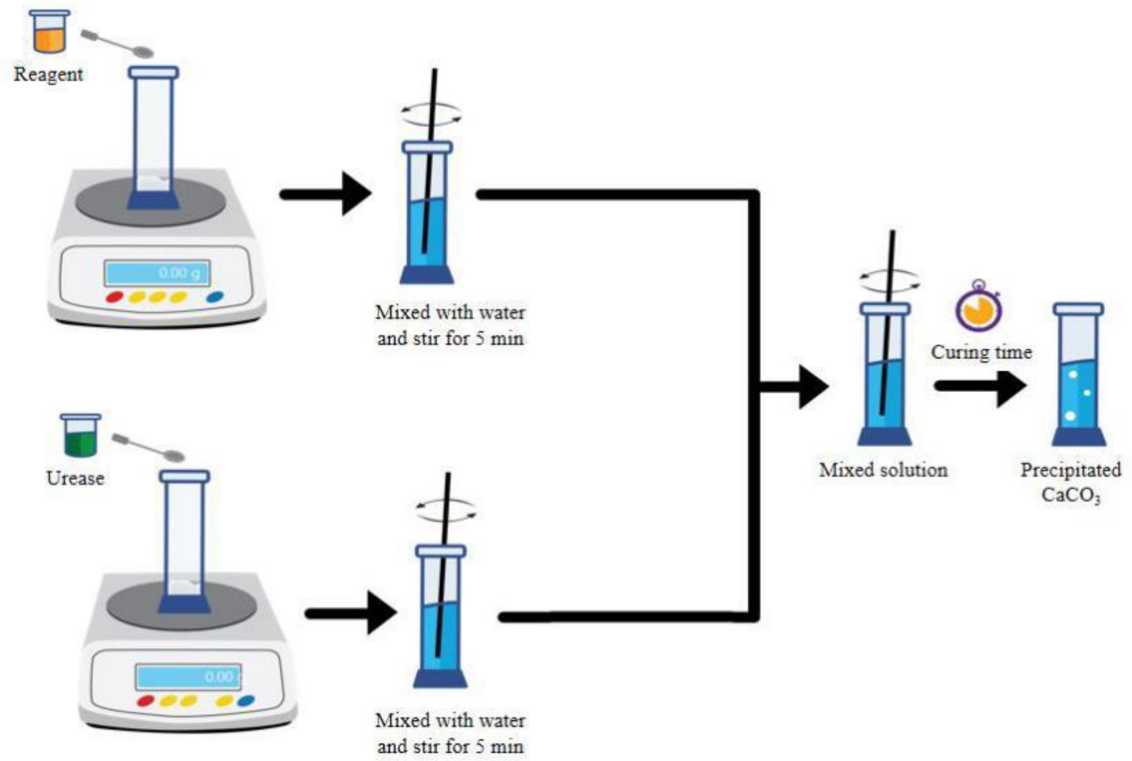

Figure 3. Precipitation test process [29]

The mass of calcite was calculated and compared with the maximum theoretical mass, thus is shown as the precipitation ratio. Several variations of urease and reagent concentrations were used to obtain the optimum combination of reagent-urease. The precipitation test is performed using the experimental conditions listed in Table 1.

Table 1. Experimental condition for precipitation test

No Sample	Urease (g/L)	Reagent (mol/L)
A1	0.5	0.5
A2	0.5	1.0
A3	0.5	1.5
A4	0.5	2.0
B1	1.0	0.5
B2	1.0	1.0
B3	1.0	1.5
B4	1.0	2.0
C1	1.5	0.5
C2	1.5	1.0
C3	1.5	1.5
C4	1.5	2.0
D1	2.0	0.5
D2	2.0	1.0
D3	2.0	1.5
D4	2.0	2.0

2.3. Unconfined Compressive Strength (UCS) Test
The unconfined compressive strength test was conducted to examine the effect of adding soybeans to the sandy soil's strength. The sand sample is prepared by pouring sand into a tube with a 5 cm diameter and 10 cm height with a relative density of 50%. Several soybean concentrations with a volume of 100 ml were added to the optimum grouting solution and, thus, are injected into the soil sample. The sample left for five days of curing time at room temperature. Prior to the USC test, the treated samples were dried using an oven for 24 hours at a temperature of 60˚C. The procedure of UCS tests is illustrated in Figure 4.

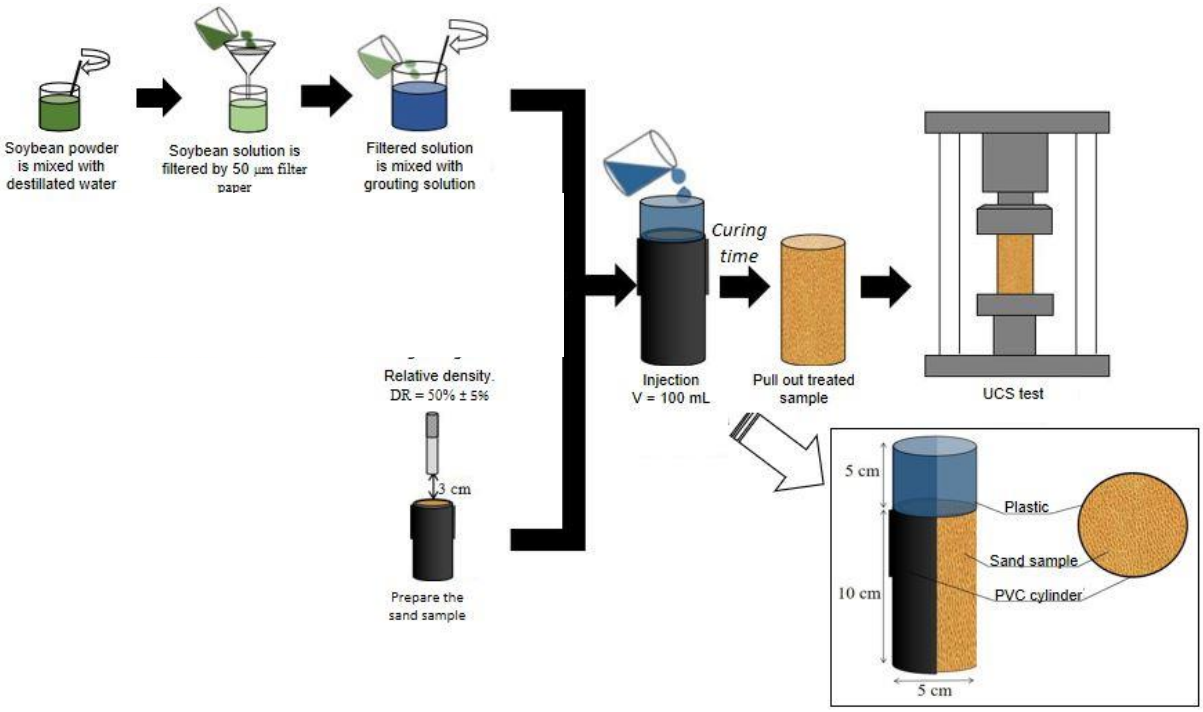

Figure 4. UCS test procedure

2.4. Calcite Quantification

Calcite quantification was carried out to evaluate the calcite content in the treated samples. The Improved soil was washed using distilled water to dissolve NH_4Cl. It is dried in an oven to obtain the dry sample. A dry sample of 20 g was collected from each sample and is washed using 0.1 M HCl to remove the calcite mineral within the soil. It was done several times until bubbles no longer appear, and thus the samples were dried again, and the dry mass is evaluated. During the acid leaching process, lost mass is calculated as mass of calcite within the soil and is shown as a percentage [21].

3. Results and Discussion

3.1 Grouting solution

Precipitation tests were performed to evaluate the calcite content in several combinations of reagent and urease enzyme. The precipitation tests result is presented in Figure 5. It shows that the precipitation ratio improved with the addition of urease. Nevertheless, the increase of reagent concentration results in a decrease in the precipitation ratio. The significant improvement is obtained when the urease and reagent concentrations were 2.0 g/L and 1 mol/L, respectively, with 90% precipitation ratio. The test results' precipitation ratio varied from 41- 86%, with the mass of calcite varies from 0.70 grams to 1.37 grams. The grouting solution with a reagent concentration of 1.5 mol/L and urease 2.0 g/L produced a relatively higher calcite mass and precipitation ratio. It reaches the precipitation ratio of 70%, with the mass of calcite is 1.29 grams. Hence, this composition is obtained as an optimum solution.

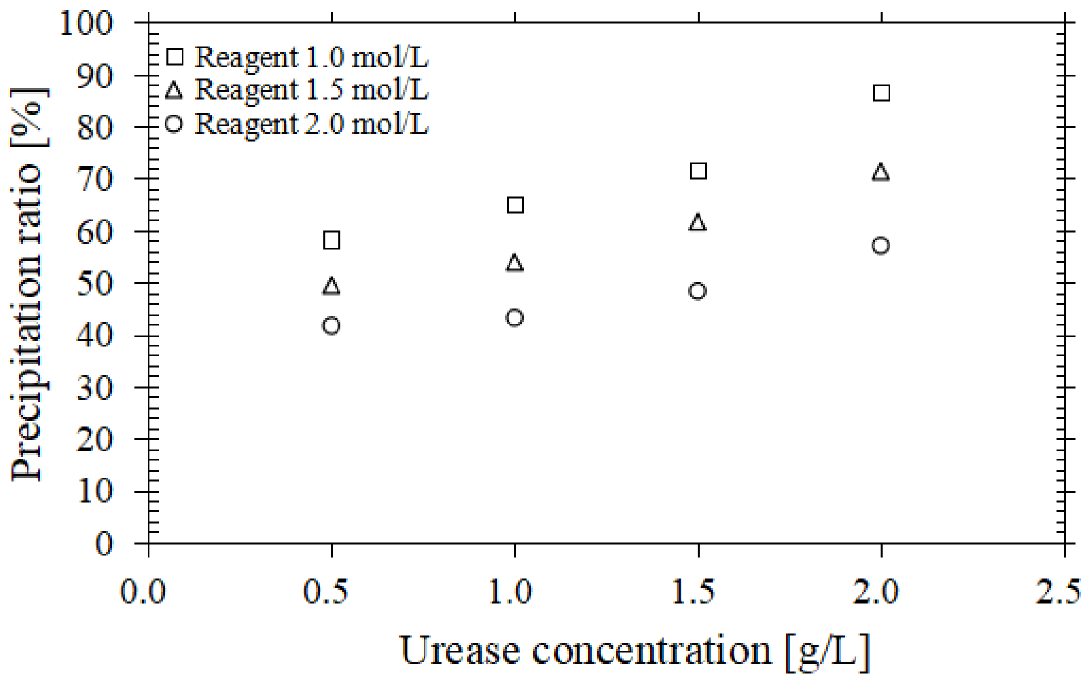

Figure 5. Evaluation of reagent and urease effect on precipitation ratio

3.2 Improvement of soil strength

The optimum grouting solution obtained from the precipitation test is prepared, and several concentrations of soybean of 40, 60, and 80 g/L are added. Thus, they are injected into the prepared soil sample, and the impact on the strength improvement and produced calcite are evaluated through UCS tests and acid leaching method, respectively. The result of the UCS test and calcite quantification of treated soil are showed in Figure 6. The addition of soybeans in the grouting solution brings about an important increasing in the shear strength and production of calcite content within the soil. The improved soil using grouting solution without soybean does not have sufficient strength to evaluate using the UCS test. The soil sample collapses when it is pulled out from the tube directly. In addition, the treated soils achieve the strength varied from 119 kPa to 168 kPa when the soybean of 40, 60, and 80 g/L are added. This result also indicated that the strength resulted in this study has sufficient strength to prevent the liquefaction, in which the soil strength has exceeded 100 kPa [30]. Increasing the soybean concentration from 40 g/L to 60 g/L succeeded in increasing the sand's strength by 13%. However, increasing the soybean concentration from 60 g/L to 80 g/L reduces the sand's strength by 30%.

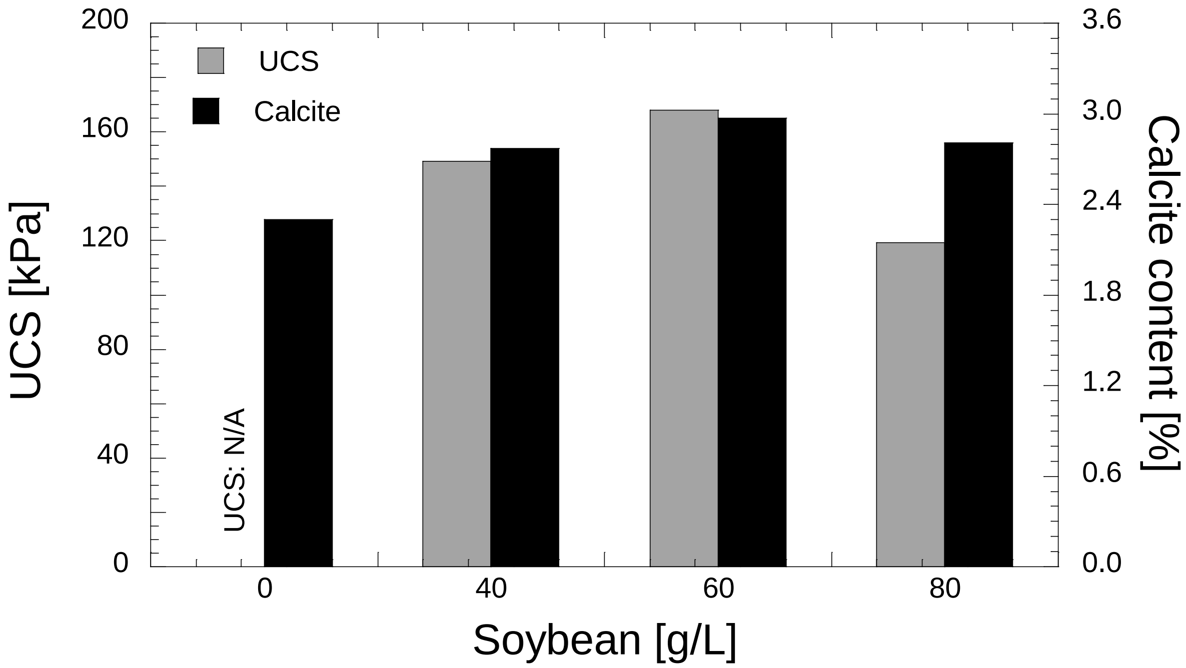

Figure 6. Impact of the use of soybean on strength and calcite content

Figure 6 shows that this study's soil strength was varied; even the soil samples' calcite content was relatively similar. It may happen because of the effectiveness of calcite formation on making bonds between particles of sand grains. Samples with the same calcite content can achieve soil strength that varies according to the efficiency of calcite bond formation in the soil [31]. In addition, varying soil strength in the increasing concentration of soybeans may occur due to the influence of the amino acid aspartate (ASP) in soybeans. ASP has a significant effect on calcite formation, which effectively reduces calcite formation [32].

Figure 7 shows the relation of soil strength and calcite content obtained in this study was compared to the similar curve of several previous studies developed by Putra et al. [22]. This result shows that the UCS resulted in this research has relatively stronger compared to the regression curves. It proved that the addition of soybeans can enhance the efficacy of the calcite precipitation as the soil stabilization method. In addition, it also indicated that soybeans are a potential material to be an alternative to the urease enzyme. Hence, the detailed investigation considering the applicability of soybean powder as a bio-catalyst in the calcite precipitation method, including the urease activity and calcite formation, should be an essential task shortly.

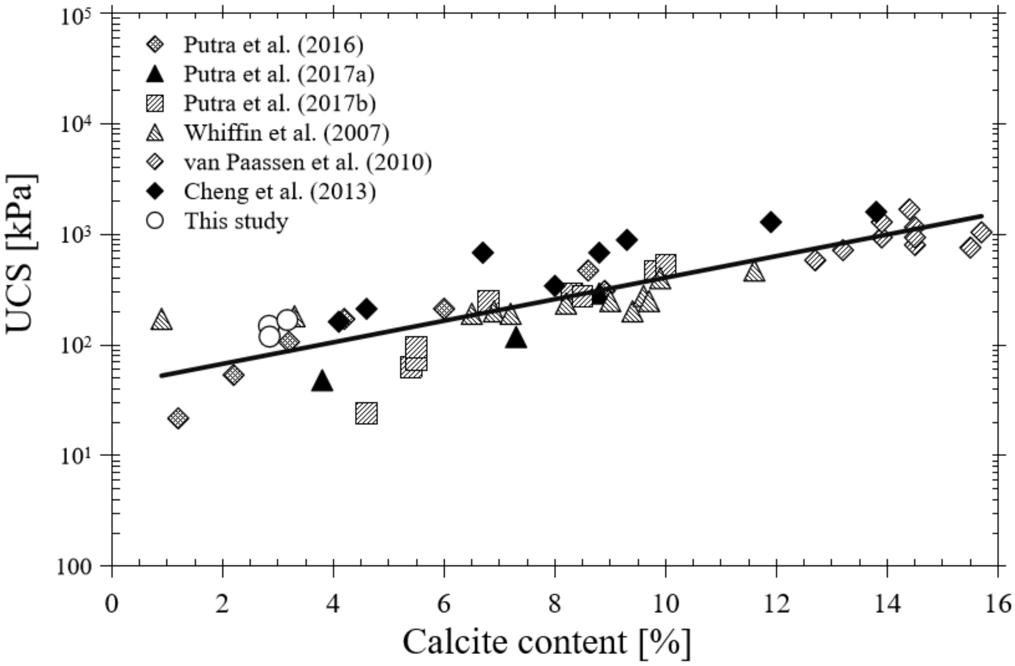

Figure 7. Correlation between sand strength and calcite content [22]

4. Conclusions

The utilization of the soybean powder as the additional material on the grouting solution of the calcite precipitation method has been evaluated. A grouting solution composing of 1.5 mol/L reagent and 2.0 g/L urease enzyme is obtained as the best composition. Thus, several amounts of soybean are were added to optimize its applicability as a soil stabilization method. The evolution of treated soil's mechanical properties was also examined through UCS tests. The calcite quantification was conducted to evaluate the precipitated calcite within the treated soil. The UCS test presented that the addition of soybean brings about a important increasing in soil strength. A maximum UCS of 168 kPa was achieved when 60 g/L of soybean was added to the grouting solution. It also promoted the calcite content of 3% of the soil mass. This result elucidated that the addition of soybeans able to optimize the applicability of the calcite precipitation method to improve the strength of liquefiable soil.

Acknowledgments

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