

# The Strength Behaviour of Eggshell Powder Substitution on Soil-lime Stabilization

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41

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# The Strength Behaviour of Eggshell Powder Substitution on Soil-lime Stabilization

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**Abstract.** This study explored the investigation into enhancing soil strength characteristics using eggshell powder (ESP) as a lime substitution on soil-lime stabilization. The ESP was naturally available while using this material, which could reduce cost and other environmental effects. The influence of varying percentages of eggshell powder as a lime substitution in changes of the strength and durability is observed based on the unconfined compression test conducted on two soil and two lime types (hydrated lime and quicklime). Influence factors were studied, including soil and lime types, ESP content, curing time, and durability against wetting-drying (w-d) cycles. The unconfined compressive strength (UCS) and the durability values of ESP-stabilized soils decreased, while ESP content increased. However, this value was higher than the unstabilized ones. The ESP substitution on soil-lime stabilization marginally affected the strength and durability of soil-lime stabilization. The UCS increased with the increasing curing period for all specimens. Soils with more clay particles reacted better to both hydrated lime and quicklime. Additionally, strength development occurred in soil-quicklime mixtures more than in soil-hydrated limes. Based on a durability test, it was known that the maximum ESP substitution was 50% from the Optimum Lime Content (OLC); beyond that content, the strength of soil might dramatically be degraded.

## 1. Introduction

The soil stabilization process can be applied to improve characteristics of the strength of those soils to make the problem soils meet geotechnical design requirements. Soil stabilization aims to enhance mechanical and physical soil properties through techniques such as compaction (mechanical stabilization) and the addition of stabilizers or admixtures (chemical stabilization). Lime is thought to be the oldest way to stabilize weak soil. The lime reacts with weak soil containing moisture and fluctuates the soil's chemical and physical properties and increases its workability, minimizes its swelling shrinkage, and multiplies the soil's load capacity [1]. The addition of lime to clay soils typically initiates four types of reactions between the lime and the clay soil constituents of silicate and aluminate. It is flocculation, exchange of cations, carbonation, and pozzolanic reaction [2-6]. Because of this, lime-stabilized soil behavior is significantly different from unstabilized soils [2].

Increased utilization of industrial residues to stabilize soil is a necessary practice for sustainable geotechnics [7-8]. The urgent need to reuse waste materials is driven primarily by environmental considerations [9], due to increased natural resource scarcity and increasing landfill costs in most countries [10]. Industrial residues such as eggshell have great potential to be used in such applications for the chemical stabilization of clayey and silty soils. Eggshell has been used as a substitute for the commercial lime to stabilize the soil. Results show that the dominant percentage component was



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calcium oxide. The high amount of calcium oxide is associated with calcium carbonate, which is the eggshell's main percentage component. Thus, the  $\text{CaCO}_3$  from eggshells can be considered quite similar to calcite calcareous from the chemical analysis [11]. The  $\text{CaCO}_3$  content of eggshells is similar to the natural limestone used in Portland Cement [12]. Furthermore, the quicklime obtained from the calcination of eggshell waste at 1000°C was found to belong to the most reactive class; the same calcium oxide was obtained from limestone [13].

Based on the findings mentioned above, many researchers conducted studies to assess the effects and effectiveness of adding Eggshell powder (ESP) as a lime (cement) substitution on soil stabilization [9, 11, 14-24]. The mixture of lime and ESP yielded marginal results to pure lime stabilization, but ESP can be replaced with no significant loss of strength and thus make the process economical [15]. The use of eggshell powder in soil improvement has no significant effect, mainly due to its loss of water absorption strength [25]. Calcium carbonate powder derived from eggshell has been found to have inferior properties compared to conventional natural limestone even with Portland cement replacements of 5% wt [26]. The addition of eggshell powder to soil has resulted in reduced plasticity characteristics, improved soil strength, and reduced soil swelling [27]. According to Oluwatuyi, et al., [9] the milled eggshell (MES) and cement (OPC) mixture at a 1:1 ratio and the 8% of MES+OPC by soil weight of stabilized lateritic soil could be used as a potential subbase material for road construction since at that content the UCS and CBR of the specimens get the maximum value. The shear strength increases with an increase in the percentage of ESP and strength is almost constant after 20% ESP [28]. Both the compressive strength and the soil modulus of the soil significantly increased in addition to 10% ESP [29]. The liquidity index which has an effect on ESP stabilized soil from SEM tests shows that the soil structure changes; it becomes dense on a mixture that contains 10% ESP [29]. A study conducted by Prasad, et al., [24] found that eggshell powder can be used to improve soil strength significantly and the optimum content of ESP was 15%. A similar result was also found on Alzaidy [11] study, that an increase in ESP content leads to an initial increase in unconfined compressive strength, California bearing ratio, and clayey soil shear strength parameters followed by a slight decrease. The optimum strength improvement requirement for ESP is about 5% by dry soil weight.

Literature has recently emerged as a contradictory finding of the strength gained on ESP-stabilized soil and the discrepancy on the optimum content of ESP. Nevertheless, the results obtained from these research works are difficult to compare, since it consists of different soil minerals and compositions, water content condition, mixing proportions, preparation, and testing of ESP-soil mixture. Findings and recommendations in the literature can be applied as a general guide. However, the factors of influence for individual sites must be verified [30-33]. This paper investigates the feasibility of using ESP as a lime substitution to improve soil strength. The Unconfined Compressive Strength (UCS) is used as a practical indicator to investigate the development of strength. Influence factors studied include soil and lime types, ESP content, curing time, and durability against wetting-drying (w-d) cycles. Its results are useful for using ESP as an environmentally sustainable resource material rather than as waste material and reduce the cost for soil stabilization applications.

## 2. Materials and Method

45

### 2.1. Soil

Two kinds of soils were used, soil A and soil B. The soil A was obtained from Kasihan Village, Bantul, Yogyakarta, and soil B was obtained from nearby borrow pits in Seyegan Village, Sleman, Yogyakarta. The soils were first air-dried at ambient temperature, and then it was sieve at #40 to remove large particles. The diameter was chosen to simplify the experimentation because limited by the diameter of the mould of California bearing ratio (CBR) and unconfined compression test (UCS) test. The physical properties of natural clay such as specific gravity, particle size, Atterberg limits, Proctor standard (maximum dry density and optimum water content), UCS test, and soil pH test were determined as follows ASTM D 854, ASTM D 6913, ASTM D 422, ASTM D 4318, ASTM D 4943, ASTM D 698, ASTM D 2166 and ASTM D 6276 [32-39] respectively. The physical properties of the soil are shown in Table 1. According to the Unified Soil Classification system (USCS) and the

American Association of State Highway and Transportation Officials (AASHTO), Soil A was classified as CH (clay with high plasticity) and A-7-5 (clayey soil, with a rating as subgrade, was fair to poor). On the other hand, soil B was silt with low plasticity (ML) and A-4 (silty soil, with a rating as subgrade, was fair to poor).

**Table 1.** Properties of soil

Properties	Values soil A	Values soil B
Specific Gravity	2.66	2.66
Sand, %	6.46	42.93
Silt, %	24.77	47.14
Clay, %	68.77	9.93
Liquid limit, %	77.50	38.12
Plastic limit, %	33.60	35.70
Plasticity index, %	43.90	2.43
USCS soil classification	CH	ML
AASHTO soil classification	A-7-5	A-4
Optimum Moisture Content, %	34.83	18.26
Maximum Dry Density, kN/m <sup>3</sup>	12.68	15.65
Unconfined Compressive Strength, kPa	121.23	125.83
pH	7.86	9.15

### 2.2. Eggshell Powder (ESP)

ESP was collected from restaurants around Universitas Muhammadiyah Yogyakarta campus, used in this study. The eggshells were properly washed and cleaned to remove the residue egg-containing that was attached to the eggshell, and the samples were then dried under sunlight for a day. The inner membrane was removed, the samples were grounded and the sieve passed through #200 (75  $\mu$ m) to achieve a uniform powdery material, a chemical reaction for larger surfaces would be completely better, faster, and more effective [15]. Table 2 presents the oxide elements of the soil and the eggshell powder. As the primary chemical constituent, the ESP consisted of 95,6% CaO, while both soils mainly consisted of silicon oxide and aluminium oxide. The total amount of oxide and self-cementing characteristics are essential considerations while preparing raw materials for the development of new cement-like stabilizers [40].

**Table 2.** Chemical composition of soil and ESP samples

Oxide composition (%)	Calcium oxide	Sulfur trioxide	Magnesium Oxide	Phosphorus Pentoxide	Silicon dioxide	Potassium Oxide	Aluminium Oxide	ferric oxide
Soil A	3.24	0.06	0	0.102	55	0.15	28.2	11.4
Soil B	0.568	0.0296	0.0258	0.108	68	1.08	24.6	4.97
ESP	95.6	2.29	0.85	0.52	0.24	0.22	0.06	0.06

### 37. Lime

For soil stabilization, a hydrated lime (calcium hydroxide) and quicklime (calcium oxide) were used, it which were mainly composed of calcium and magnesium hydroxides. The lime was produced and sold in Yogyakarta. The lime was pulverized, sieved using #200, and the portion passing the sieve was used.

#### 2.4. Optimum Lime Content (OLC)

The requirement of lime for soil-lime stabilization, the method described in ASTM D 6276 [39] is used to estimate soil-lime proportion. The concept of OLC in the field of lime stabilization was introduced by Eades and Grim [41], which was defined as the quantity of lime that can provide sufficient quantity of free calcium required for short-term soil improvement in terms of its workability and plasticity, as well as long-term enhancement of its strength, rigidity, and durability [42]. A series of specimens that contain a range of percentages of lime content in soil were being prepared. Measurements of pH were performed on specimen slurries to determine the minimum lime content of the soil-lime mixture in order to obtain a pH of at least 12.4. In this test method the pH of at least 12.4 achieved results from the free lime remaining in the soil-lime mixture, upon the addition of lime the alkalinity of the soil increased. As the pH value increased, the pozzolanic reaction increased and lead towards better flocculation. When mixed with lime, the clay underwent major structural transformations [2]. Figure 1 describes the Optimum Lime Content (OLC) of the soil sample. For soil A and B stabilization using hydrated lime and quicklime, the OLC was 8% and 6% by weight of dry soil respectively. Moreover, pH testing could offer suitable alternatives to extensive and time-consuming UCS testing for quicker determination of the optimum lime content, which could, in turn, offer considerable cost savings [3].

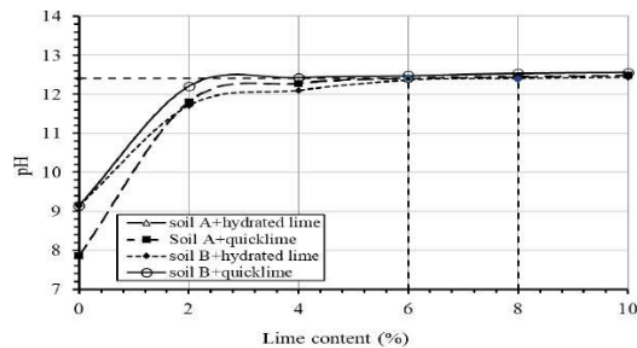


Figure 1. Determination of optimum lime content (OLC)

#### 2.5. Soil Compaction

The test to determine the optimum moisture content (OMC) and maximum dry density (MDD) was carried out under ASTM D698 [37] at the standard energy level of the Proctor. The optimum water content and maximum dry density for the unstabilized and stabilized soil using 8% hydrated lime and 6% quicklime (OLC) are presented in Table 3. The maximum dry unit weight and optimum moisture content of each soil-lime mixture were used to compact specimens for UCS test.

Table 3. The Compaction parameter of the soils.

Type of soil mixture	Maximum dry unit weight (kN/m <sup>3</sup> )	Optimum moisture content (%)
Soil A (untreated)	12.68	34.83
Soil A+8% hydrated lime	13.12	16.46
Soil A+6% quicklime	13.12	18.77
Soil B (untreated)	15.65	18.26
Soil B+8% hydrated lime	15.32	20.41
Soil B+6% quicklime	15.02	20.56

### 2.6. Sample preparation

All the samples tested were prepared in the laboratory in order to conduct a precise parametric study. Based on the method of E<sub>10</sub>s and Grim [41], the soil samples were treated with 8% hydrated lime and 6% quicklime giving a pH value of 12.4. The Optimum Lime content (OLC) percentage was gradually reduced and substituted by an appropriate percentage of ESP in the following ratio: 8% hydrated lime+0% ESP, 6% hydrated lime+2% ESP, 4% hydrated lime+4% ESP, 2% hydrated lime+6% ESP, 8% ESP. For quicklime stabilization, percentage of quicklime:ESP ratio in the following; 6% quicklime +0% ESP, 4.5% quicklime +1.5% ESP, 3% quicklime+3% ESP, 1.5% quicklime+4.5% ESP, and 6% ESP. The two specimens were prepared per lime-ESP content ratio, following the same procedures for mixing and compaction. The soil was thoroughly mixed in a dry state with the predetermined amount of E<sub>19</sub> and lime until a homogenous and uniform appearance of the mixture were achieved. The required amount E<sub>55</sub> water was then added to the mixture, which was thoroughly re<sub>28</sub>xed. The wet mixture was then stored in plastic bags and left for 24 hours. In this research, the cylindrical specimen<sub>40</sub> with a diameter of 36 mm and a height of 72 mm were used. The soil samples were compacted to optimum moisture content, and maximum dry unit weight represented the mixture soil-lime<sub>47</sub> OLC compaction curve according to the ASTM D-698 [37] procedure presented in Table 3. To prevent any changes in the moisture content of specimens, the<sub>26</sub>mpact specimens had been wrapped in a plastic bag. All samples of stabilized soil were cured at room temperature for 7, 14, and 28 days. The UCS test was conducted following the provisions of ASTM D 5102 [43]. Durability assessment was conducted by ascertaining resistance to a loss in strength from stabilized samples; the four similar specimens were prepared; the value was estimated by dividing the UCS of stabilized samples cured under controlled conditions for seven days and then soaking in water for another one day. It was then compared with the UCS of another set of stabilized samples cured under controlled conditions for seven days. The same way was done for samples with a curing period of 14 days, compared with samples with a curing time of 7 days. After that, it was given a wet-dry (w-d) cycle for three times (one wet-dry cycle is one day of immersion, one day of drying at room temperature).

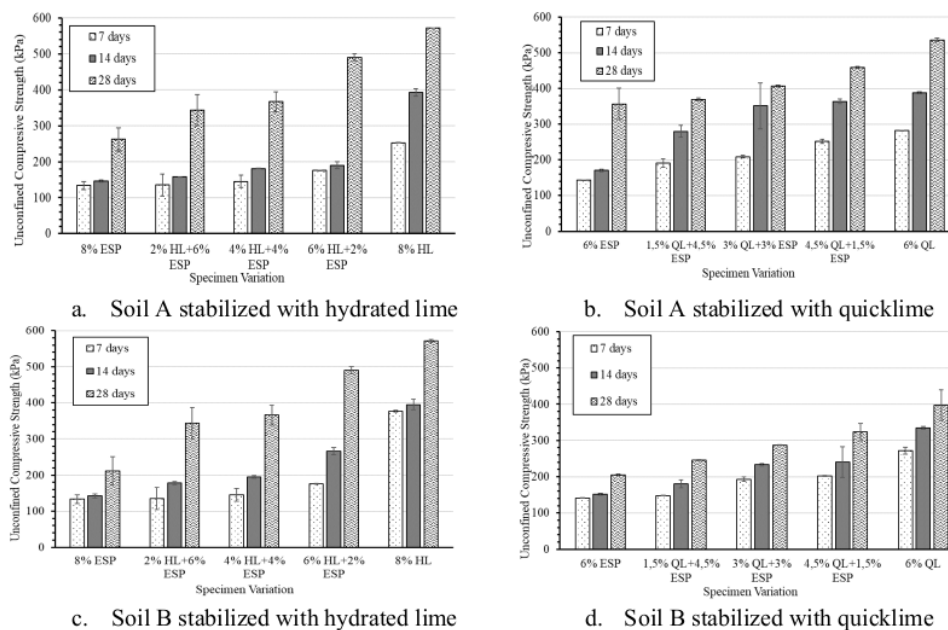
## 3. Result and Discussion

### 3.1. Compaction test result

Table 3 shows the standard compaction test result on unstabilized dan soil-lime stabilization. The maximum dry density (MDD) and optimum moisture content (OMC) for the soil A and soil B with the addition<sub>20</sub> of both quicklime and hydrated lime showed different trends. For t<sub>20</sub> soil A, the addition of lime, the MDD increased while OMC<sub>6</sub> decreased. On the other hand, soil B the MDD decreased, and OMC increased. Several researchers revealed that the change in dry density occurs due to both the size of the particles and the specific gravity of the soil used and the stabilizer [44]. Okonkwo et al.,<sub>48</sub> used eggshell ash along with side cement as stabilized material and obtained a similar trend. The decrease in MDD may be attributed to the agglomeration of the stabilizing binder, and the lateritic soil (Clayey sand) intensify<sub>14</sub> to form dense aggregates by the cementitious nature of the binder. Adding lime to clay materials increases its optimum moisture content and reduces its maximum dry density for the same compaction effort. The reduction in dry density could be due to the immediate formation of cement products that reduce compatibility and hence the density of the soil being treated [46]. The increase in OMC can be due to the stabilization of the lime requiring more moisture for calcium ion dissociation and subsequent hydration [9]. The following reasons could explain this behaviour: the added lime causes th<sub>12</sub>gregation of the particles to occupy larger spaces and thus alters the effective<sub>35</sub>ding of the soils; the specific gravity of the lime is generally lower than that<sub>64</sub> he tested soils, and the pozzolanic reaction between the clay presented in the soils and the lime is responsible for the increase in OMC [47]. For soil A using hydrated lime as stabilized material, MDD increased while OMC decreased. The decrease in OMC could have been due to<sub>34</sub> lower affinity of stabilized material (in this study was Hydrated lime) to water. Additionally, the increase in MDD is likely due to the relatively higher specific gravity of the hydrated lime [48].

### 3.2. The effect of soil types, lime types, and ESP on the unconfined compression strength

Figure 2 shows the average unconfined compressive strength of specimens. Lime-stabilized soil increased compressive strength ( $q_u$ ). The  $q_u$  of lime-stabilized soil was about 2 times that of unstabilized soil on curing times 7 days in both soil types. When Soil A was stabilized using hydrated lime and quicklime, the  $q_u$  increased from 121,23 kPa to 252,89 kPa and 281,91 kPa respectively, while for Soil B, the  $q_u$  increased from 125,83 kPa to 377,13 kPa and 281,91 kPa. Based on the UCS results, it can be seen that overall curing period, soil A stabilization using quicklime has slightly greater UCS value than soil B. In the stabilization of both soils, soil A and B used hydrated lime, the UCS values of the two soils were almost the same. According to Amadi et al., [48] quicklime-stabilized soil had higher UCS values than those stabilized with hydrated lime, and a much stronger stabilized product was produced on the CH soil in his study. Research has shown that there is more development of strength in soil-quicklime mixtures than in hydrated lime [46, 49]. Also, very rapid stabilization of water-logged sites or very wet materials with the use of quicklime was achieved [46]. On the other hand, hydrated lime is used extensively to stabilize soils with a high content of clay where its main advantage is to raise the plastic limit of clayey soil [50].



**Figure 2.** The Variation of unconfined compression strength on the lime-ESP mixtures

The increase in shear strength of the stabilized soil may be attributed to the physicochemical phenomena, namely the exchange of cations between the lime and the negatively charged clay particles along with the mechanism of flocculation agglomeration that made soil particles larger which can resist the compressive load applied more effectively than unstabilized ones [9, 51]. These develop rapidly and produce immediate improvements in soil properties, including uncured strength and properties of load-deformation [48, 49]. Furthermore, later pozzolanic reactions occur between the calcium ions and the clay minerals silica and alumina, in turn, leads to the formation of cementitious products such as calcium-silicate-hydrates (CSH), calcium aluminium-hydrates (CAH), and calcium-aluminium-silicate-hydrates (CASH), which are also responsible for the increase in strength [31, 48-49].

The substitution of the ESP in the lime-soil mixture decreased the compressive strength by about 50% for both soil A and soil B and both hydrated lime and quicklime. The higher the percentage of



ESP that substituted the lime, the lower the soil strength. However, the unconfined compressive strength of the ESP-soil mixture was higher than unstabilized soil. Increased unconfined compressive strength of soil with an ESP mixture comparing to the unstabilized soil was approximately 10% -17% for soil A and 5% -11% for soil B by substituted lime with the ESP 6% and 8%. The lower UCS value could be attributed to the lower reactivity of calcium oxide from eggshell waste which was related to its larger particles with smooth surfaces and lower specific surface area in comparison to limestone calcium oxide [13]. The result is in agreement with previous research, which reported a decrease in compressive strength of lime (or cement) stabilized soil on replacement of lime (or cement) with ESP [15, 25-26].

### 3.3. The effect of curing time on unconfined compression strength

Increased unconfined compressive strength demonstrated the improvement in mechanical behaviour with an increased curing period. Figure 3 shows the strength development during the curing period. Furthermore, investigating the effect of the curing time shows that the UCS of the stabilized specimens increases by increasing the age of the specimens for all three curing times. Reactions such as cation exchange and dissociation reactions result in immediate alteration in soil plasticity and workability. Long-term pozzolanic reaction produces gel-like and fibrous cementing compounds, CSH and CAH, which enhance the bond between the soil particles thus increasing the soil strength [11, 31]. Depending on the rate of chemical decomposition and hydration of the silicates and aluminates, long-term reactions may require weeks, months or even years to complete [52].

The rate of increase was significant from 7 days to 28 days, but the rate of UCS increase for specimens of hydrated lime was slower at curing time seven days to 14 days than that for specimens of quicklime. According to Bell [46]; Cherian and Arnepalli [49]; Amadi and Okeiyi [48] in soil-quicklime mixtures, there were more strength development, and very rapid stabilization of water-logged sites than in hydrated lime.

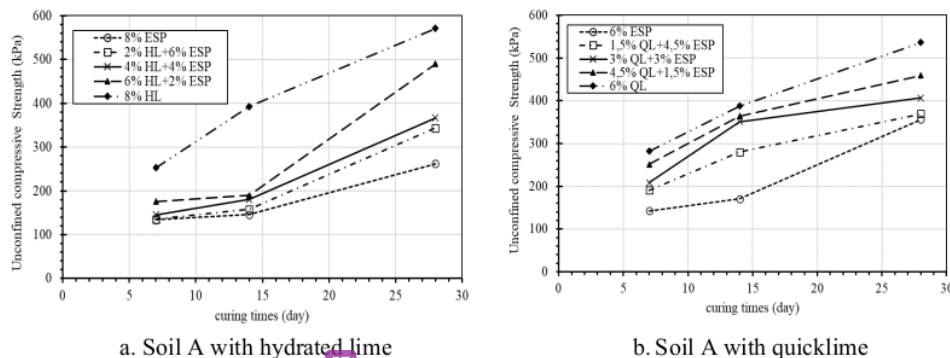
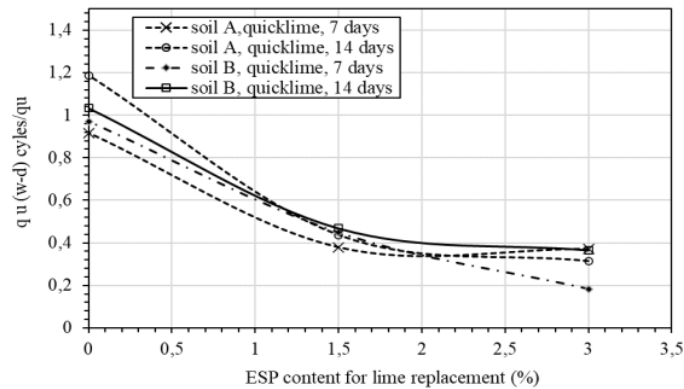


Figure 3. The development of Unconfined Compression Strength as a function of curing times

### 3.4. The specimen durability

Figure 4 shows the strength ratio between soaked (specimens objected with w-d cycles) and those without w-d cycles at a certain curing time. However, the specimens with 6% ESP and 4.5%ESP was not plotted for the soil because the sample degraded during so<sup>50</sup>ng, and could not be tested. It is quite clear that the quantity of lime is quite important in terms of the durability of the soil-lime mixtures. When the content of ESP more than 3% (this content was 50% ESP substitute quicklime), the specimen undergoes degradation. The more ESP substituted the lime, the lower the strength ratio between the specimens undergoing w-d cycle than those without w-d cycles. The durability in longer curing time was marginally higher. Wetting-drying cycles cause some cementation bonds created by lime treatment breakage and damage, and it could be attributed to decreasing the strength of specimens

on the wetting condition. Another possible reason to attribute to the drying's detrimental effect could be the fact that it stops the pozzolanic reaction that requires a certain degree of humidity in the soil[2].



**Figure 4.** The strength ratio between  $q_u$  applied w-d cycles and  $q_u$  without w-d cycles versus ESP content

#### 4. Conclusion

The unconfined compression test and the durability against wetting-drying cycles of ESP substituted soil-lime stabilization have been successfully tested and discussed. The present study designed to determine the effect of using ESP as a lime substitution to improve soil strength. The following conclusions can be drawn,

1. The substitution of the ESP in the lime-soil mixture decreases the compressive strength by about 50% for both soil A and soil B and both hydrated lime and quicklime. The higher the percentage of ESP that replaces the lime, the lower the soil strength. However, the unconfined compression strength of the ESP-soil mixture is higher than unstabilized soil.
2. Soils with more clay particles react better to both hydrated lime and quicklime, while in soil-quicklime mixtures more strength development occurred than in soil-hydrated limes.
3. The UCS of the stabilized specimens increases by increasing the curing period of the specimens.
4. The more ESP substituted the lime, the lower the strength ratio between the specimens undergoing w-d cycle than those without w-d cycle. The durability in longer curing time is marginally higher.

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