

The effect of egg shell powder on the compression strength of fine-grained soil

Niken Silmi Surjandari¹, Raden Harya Dananjaya^{1,*}, and Ely Jauharotus S²

¹Civil Engineering Department, Universitas Sebelas Maret, Surakarta, Indonesia

²Undergraduate student, Civil Engineering Department, Universitas Sebelas Maret, Surakarta, Indonesia

Abstract. High plasticity clay has several problems including a high plasticity index and low bearing capacity. Stabilization of high plasticity clay is still extensively explored, especially for a low-cost and easily obtainable material. The purpose of this research is to study the effect of eggshell powder (ESP) on high plasticity clay. This research uses a soil sample obtained from Jenggrik Village, Ngawi Regency, East Java. Furthermore, the problematic soils at liquidity index of 0 – 1.25 are mixed with the ESP in various percentages, i.e. 0%, 10%, 15%, 20%. Several laboratory tests have been conducted to examine the effects of the mixtures, such as index properties, unconfined compressive strength and Scanning Electron Microscopy (SEM). The result indicates that the liquidity index affects the soil stabilized by ESP. SEM test results show that the soil structure changes, it becomes dense on a mixture containing 10% ESP. The conclusion of this research is that the higher the liquidity, the lower the strength.

1 Introduction

Fine-grained soil, especially clay, having a high-water content tends to be a problematic soil. This soil usually has low strength and a large volume change. One of several regions having abundant problems with fine-grained soil is Jenggrik Village, Kedunggalar, Ngawi District, East Java. One of the methods to overcome these problems is the stabilization with additives to increase the soil strength. The additive used in this research is eggshell powder (ESP), which is environmentally friendly and low-cost. The mineral content of ESP can also be used as an added ingredient and is considered as an active lime replacement because it has similar mineral contents, i.e. CaO (99.385%), Al₂O₃, SiO₂, Cl, Cr₂O₃, MnO and CuO [1]. If CaO reacts with water in the soil mixtures there will be flocculation so that the chemical elements in the eggshell powder merge with the soil. Furthermore, it produces C-S-H, A-S-H or C-A-S-H is strong [2].

The addition of eggshells is very effective due to the rapid growth of the bread industry in Indonesia. So, the use of eggshell as an additive material can reduce environmental

* Corresponding author: nikensilmisurjandari@staff.uns.ac.id

pollution. After soil is mixed with eggshells, the UCS tests are conducted to find out the compressive strength of the mixture.

With the addition of ESP there is a considerable change in soil properties. [3] reported the increase of permeability and the consolidation coefficient due to the addition of ESP. ESP gradually decreases the plasticity index from 18.35% to 3.6%. It happens because ESP produces loose soil. In another report, ESP increases the soil compressive strength by 25% in increments of 0.5% ESP and reaches maximum compressive strength at 3% ESP. The increase of the strength of the mixture is caused by the formation of calcium silicate hydrate [4]. [5] also conducted soil stabilization using ESP. The result is the decrease of plasticity index due to increase of ESP and increase of the UCS and CBR until it reached maximum at the addition of 30% of ESP.

Another study mentions ESP as a lime replacement, which increases the compressive strength of soil from 59.64 kN/m² to 93.5 kN/m² in the addition of 3% of lime + 4% of ESP due to the pozzolan reaction [6]. [7] observed the effects of ESP on an unconfined compressive strength (UCS) in three different samples. The UCS values increase from 79.64 to 284.66 kN/m², 204.86 to 350.10 kN/m², and 240.4 to 564.6 kN/m² in each sample. [8] studied the effect of a combination of lime and ESP on soil strength, the result shows that the soil strength reaches maximum when the mixture contains 5% lime and 5% ESP.

In another study, 2%, 4%, 6% and 8% of ESP were mixed on the laterite inorganic soil, both cement and ESP addition increase the density of the soil [9]. This research used four variations of liquidity index (LI), i.e. 0, 0.25, 1 and 1.25. The percentages of ESP used were 5%, 10%, 15%, and 20% by the dry weight soil. The purpose of this study was to determine the effect of ESP addition and to produce new innovations in soil stabilization.

2 Materials and methods

The soil samples were taken from Jenggrik Village, Kedungalar, Ngawi District. The disturbed soil was manually taken at a depth of 1 to 2 meters from the surface. According to USCS, the soil belongs to high plasticity clay (CH). Then, the soil is dried using an oven for 24 hours at 110°C. Moreover, the Atterberg's Limits tests and Grain-size analysis were conducted.

Eggshell as an additive is an organic waste of food traders that have not been optimally utilized. Not only does it reduce pollution, eggshell also has the same chemical composition with lime, so it can replace lime. Before the powdering process, the eggshell is washed and cleaned for 24 hours at 110 °C. Then the eggshell is pounded until the size is less than 0.075 mm. Fig. 1. (a) shows the eggshell after being oven-dried and (b) the ESP powder.



Fig. 1. (a) The eggshell after the oven-drying process, (b) ESP powder.

In the next step, both the soil and ESP are tested for mineral contents. Four different weight ratios of ESP (i.e. 5%, 10%, 15%, 20%) and LI (i.e. 0, 0.25, 1, 1.25) will be used. Then each of soil samples in various LI is mixed with various weight ratio of ESP.

The mixed samples are sterilized for 3 days. Furthermore, Atterberg’s Limits tests, Grainsize Analysis, UCS tests, and Scanning Electron Microscopy (SEM) tests are conducted. This test is to determine the effect of ESP addition on high plasticity clay.

3 Result

3.1 Mineral content of soil and ESP

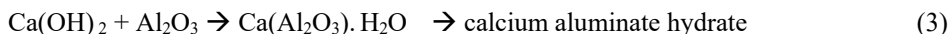
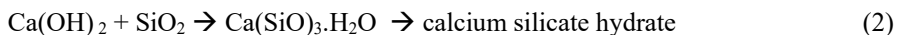
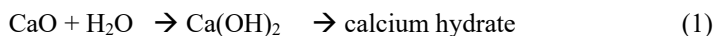
Mineral content on soil and ESP were tested with X-Ray Fluorescence (XRF). This test is to find out the mineral content in soil and ESP as shown in Table 1.

Table 1. The result of XRF soil and ESP.

No	Mineral Content	Soil (%)	ESP (%)
1	SiO ₂	33,83	2,64
2	K ₂ O	-	-
3	P ₂ O ₅	-	1,00
4	Fe ₂ O ₃	20,84	-
5	CaO	10,57	77,29
6	Al ₂ O ₃	9,66	1,12
7	MgO	3,41	2,30
10	Na ₂ O	-	11,6
11	Other minerals	21,69	4,05

XRF test results showed that soil samples contain 43.49% silicate compounds (SiO₂) and aluminate (Al₂O₃). Fine-grained soil tends to swell when the majority of the soil minerals are montmorillonite (Al₂O₃·4SiO₂·2H₂O). The broad tetrahedral surface of the montmorillonite mineral causes a large amount of water absorption. Due to the montmorillonite content being above 35 %, according to [10] this soil belongs to expansive soil.

In ESP, there is around 77.29% of CaO (Table 1). When CaO reacts with water and soil, it will cause a pozzolanic reaction and form calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H) or calcium silicate aluminate hydrate (C-S-A-H) [2]. Chemical reactions that occur between CaO, water and soil are:



3.2 Index properties mixed soil

The liquid limit (LL) decreases along the increase of ESP. The maximum decrease of LL due to ESP addition occurred at the addition of 20% of ESP, i.e. about 33.08% decrease. The addition of ESP significantly increases the Plastic Limit (PL). The maximum PL is found at addition of 10% of EPS. It would increase about 29.32 %. After PL reaches the maximum at the addition of 10 % of ESP, the PL gradually decreases along the increase of the ESP content.

The change of PL due to ESP affects the soil plasticity index. The PI decreases with an increase of ESP content until it reaches minimum at 10 % of ESP, and then PI increases gradually. This is because ESP has a high Ca(OH)₂ and MgO content. If Ca(OH)₂ and MgO

are mixed with clays having high montmorillonite content, Ca^{2+} and Mg^{2+} ion will exchange with Na^{+} and K^{+} ions, and then it decreases the plasticity index [2]. The results of testing the complete index properties are shown in Table 2.

Table 2. Result of index properties mixed soil.

Parameter	Original Soil	Soil + ESP (%)			
		5	10	15	20
<i>LL</i>	110,33	95,43	94,86	91,49	77,25
<i>PL</i>	43,06	57,32	72,38	60,75	47,61
<i>PI</i>	67,28	38,10	22,48	30,74	29,65

3.3 Result of UCS testing and young modulus analysis (*E*)

The results of UCS testing are shown in Table 3. The test was conducted on four conditions of *LI* and five variations of ESP content

Table 3. Result of UCS test mixed soil.

	ESP contents (%)	<i>LI</i>			
		0	0.25	1	1.25
q_u (kN/m ²)	0	36,80	34,01	0	0
	5	262,25	73,97	7.32	0
	10	440,02	81,76	14.50	1.85
	15	412,51	95,11	10.96	1.86
	20	281,97	59,19	3.70	0
<i>E</i> (kN/m ²)	0	27,35	8,49	0	0
	5	46,66	13,30	4.62	0
	10	78,29	17,42	5.10	3.45
	15	75,41	17,10	6.29	3.75
	20	51,26	15,47	5.89	0

The addition of ESP affects the compressive strength of the soil. This is shown by the increase of q_u . q_u tends to increase until it reaches a maximum at 10% of ESP, and it decreases again gradually. At *LI* = 0, the q_u increases about 1195.71 %. This is because there is a pozzolan reaction between CaO with the soil that makes soil harder [2]. The addition of ESP in soil having *LI* = 0 and *LI* = 0.25 increases the q_u significantly, while the addition of ESP in soil having *LI* = 1 and *LI* = 1.25 only gives a small increase of q_u .

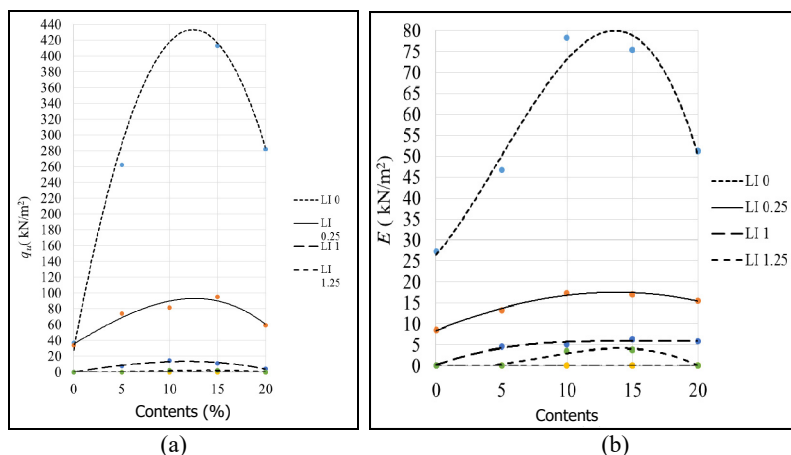


Fig. 2. (a) UCS graph, (b) Young modulus analysis graph.

The increase of q_u due to addition of ESP depends on LI of the soil. At $LI = 0$, the increase of q_u is higher than the others. Soil moisture contributes to the strength of the mixture. The water content at $LI = 0$ accelerates the pozzolan and ESP reaction.

Before the soil is stabilized, the soil belongs to very soft clay. Fig. 2. (b) shows that the value of E after the addition of 10% of ESP at $LI = 0$ is 78.29 kN/m^2 , which belongs to the hard clay according [11]. While the others are still classified in soft clay, but there is an increase of E .

3.4 Result of scanning electron microscopy (SEM) test

Scanning electron microscopy (SEM) is used to know the microscopic soil structure before and after fine-grained soil stabilization. The magnification used in the SEM test results is 200 times as it is considered clear to observe. SEM test results are shown in Fig. 3.

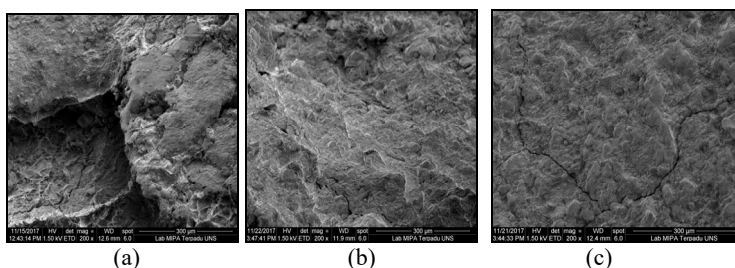


Fig. 3. (a) SEM original soil, (b) SEM of 10% ESP and $LI 0$, (c) SEM of 10% ESP and $LI 1$.

The original soil SEM test results show that the soil structure has many cavities and cracks. Fine-grained soil in a dry state or lack of water will have cavities and cracks that cause soil strength to decrease. While the SEM results of the ESP-soil mixture looked denser due to the reaction of pozzolan resulting in bonds between the soil grains, so that the soil grains become solid and denser. The reaction is also called the cement reaction. Pozzolan reaction forming calcium silicate hydrate (C-S-H), calcium aluminate hydrate (C-A-H) or calcium aluminate silicate hydrate (C-A-S-H) is strong enough and it can increase the value of UCS.

LI also affects the speed of the pozzolan reaction between soil and ESP. The higher the LI value the slower the reaction process occurs. The slow reaction affects the compressive strength of soil and soil structure as shown in Fig. 3. The best soil structure is the mixture having $LI = 0$ where the surface looks very dense and solid due to optimum pozzolan reaction.

4 Conclusion

The following conclusions can be made from this research:

- The addition of ESP can decrease the index of plasticity by about 299.288% (from 67.28% to 22.48%)
- Compressive strength of soil increases significantly in the addition of 10% of ESP at soil having $LI = 0$ around 1195.71% (from 36.02 kN/m^2 to 403.23 kN/m^2)
- The Young modulus increases significantly in the addition of 10% of ESP at soil having $LI = 0$ around 286.252% (from 27.35 kN/m^2 to 78.29 kN/m^2) and belongs to hard clay.
- SEM test results show that the best surface structure is at the addition of 10% of ESP at soil having $LI = 0$.

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