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Soil stabilization using eggshell powder and its effect on unconfined compressive strength (UCS) values

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ABSTRACT

Soil in road pavement construction has an important role as the foundation for the structure supporting the load above it. The damage that occurs in road construction also often due to subgrade soil that does not have good bearing capacity, therefore soil reinforcement or stabilization is needed to improve its strength. The road section in Cibingbin Village, Cibaliung subdistrict, Pandeglang Regency was damaged due to a lack of soil bearing capacity, where through field CBR tests it was discovered that the CBR value of the soil was 3% less than required. Soil strengthening can be done by adding additional substances to the soil which can increase its strength and bearing capacity. Eggshell powder was chosen in this research as an additive to see its effect on soil strength. Soil strength is tested through unconfined compression stress (UCS) testing in the laboratory. Apart from that, the effect of adding eggshell powder on the physical properties of the soil was also studied. Variations in adding eggshell powder were taken in varying percentages 0%, 2%, 4%, 6%, 8%, 10%, 12% and 14%. The results of testing the physical properties of the soil showed that the original soil type was classified as organic clay with high plasticity (CH). The UCS test results on the original soil had a strength (q_u) value of 1.6 kg/cm2, and the adding eggshell powder could increase the q_u value which got optimum value at the percentage 12% eggshell powder with 0 and 3 days of curing of 2.851 kg/cm^2 and 3.386 kg/cm^2 respectively. It can be concluded that the addition of eggshell powder can increase the soil strength. The consistency of the clay soil changes to become stronger and based on the UCS value the clay soil becomes stiffer.

ABSTRAK

Tanah pada konstruksi perkerasan jalan memiliki peranan penting sebagai landasan struktur pendukung beban diatasnya. Kerusakan yang terjadi pada konstruksi jalan juga banyak terjadi akibat tanah dasar yang tidak memiliki daya dukung yang baik, oleh karena itu diperlukan perkuatan tanah untuk memberbaiki kekuatannya. Ruas jalan di Desa Cibingbin kecamatan Cibaliung Kabupaten Pandeglang mengalami kerusakan akibat kurangnya daya dukung tanah, berdasarkan uji CBR lapangan diketahui bahwa nilai CBR tanahnya hanya 3% kurang dari yang disyaratkan. Perkuatan tanah dapat dilakukan dengan menambahkan zat tambah pada tanah yang dapat meningkatkan kekuatan dan daya dukungnya. Serbuk cangkang telur dipilih dalam penelitian ini sebagai zat tambah untuk dilihat pengaruhnya terhadap kekuatan tanah. Kekuatan tanah diuji melalui pengujian uji tekan bebas (unconfined compression stress, UCS) di laboratorium. Selain itu pengaruh penambahan serbuk cangkang telur terhadap sifat fisik tanah juga diteliti. Variasi penambahan serbuk cangkang telur diambil dengan prosentase bervariasi yaitu 0%, 2%, 4%, 6%, 8%, 10%, 12% dan 14%. Beberapa pengujian sifat fisik sebelum dan sesudah penambahan zat tambah juga dilakukan seperti uji kadar air, berat jenis butir, analisa besar butir, batas-batas Atterberg, serta kadar air optimum dari uji pemadatan.Hasil pengujian sifat fisik tanah didapatkan jenis tanah pada lokasi penelitian adalah tanah lempung organik dengan plastisitas tinggi (CH). Hasil pengujian UCS pada tanah asli memiliki nilai qu 1,6 kg/cm2 dan terjadi peningkatan hingga optimum pada penambahan serbuk cangkang telur 12% di 0 dan 3 hari pemeraman dengan nilai qu 2,851 kg/cm^2 dan 3,386 kg/cm^2. Dapat disimpulkan bahwa penambahan serbuk cangkang telur pada presentase 12% dapat meningkatkan kekuatan tanah. Konsistensi tanah lempung berubah menjadi lebih kuat dan berdasarkan nilai UCS tanah lempung menjadi semakin kaku.

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1. Introduction

Subgrade soil is the lowest layer that functions as a load-bearing layer and supports the construction of the road pavement above it. This research took soil samples located on roads in Cibingbin Village, Cibaliung District, Pandeglang Regency. The condition of the road at that location was damaged due to the load of traffic passing through it (see Figure 1). Based on initial tests in the laboratory and DCP (Dutch Cone Penetration) tests in that location, the soil sample can be classified as clay with a plasticity index of 37.85% and a CBR value of 3%. The bearing capacity of the soil with a CBR of 3% does not meet the standards for road base soils based on the provisions of the Indonesian National Standards of the Department of Public Works which require a minimum CBR of 6%. Soil improvement efforts need to be carried out to increase soil strength by increasing its CBR value. The CBR value represents the strength of the soil based on the soil's ability to withstand penetration of the load above it. Soil strength can also be represented by the unconfined compression strength (UCS) value resulted in the laboratory. In this research, the utilization of adding additives using eggshell powder (ESP) as a soil stabilization material and its effect on the soil unconfined compression strength value will be studied. Eggshell powder utilization is taken as part of a program to utilize household waste into additives that can increase soil strength.

The eggshell powder is one of the food wastes that is often found and is rarely recycled. According to [1], eggshell powder contains 77.29 CaO, and the rest consists of Al203, P2O5, MgO, Na2O, and other minerals. CaO (Calcium Oxide) is generally known as raw limes which is good for use in soil stabilization, so eggshell powder can replace lime which is often used as an additional soil stabilization material. The use of limes, which is much more expensive than eggshell powder, is also one of the reasons of the using of eggshell powder as material additives in this research.

Some methods of improving soil strength by utilizing household and industrial wastes have been carried out by several previous researchers, such as stabilization using palm ash by [2-3] and [4-6] using a mixture of fly ash, and [7] using a lime mixture studied for its effect on the soil unconfined compressive strength. Based on those researches, it can be concluded that soil stabilization with additives such as lime, palm ash waste and fly ash can improve soil physical dan mechanical properties to make it more stable. This research aims to see the effect of other added substances such as eggshell powder (ESP) as a soil stabilization material based on research references on eggshell powder that have been carried out previously. Several studies on soil stabilization using eggshell powder have been carried out by several previous researchers such as [1], [8], and [9]. Based on their results, eggshell powder is an additional material that can increase the compressive strength value of soil.

Several studies on soil stabilization using eggshell powder have been carried out previously and are the main reference basis for this research, such as [8] which examining the effect of eggshell powder on soil properties index. In the research, powder content variations were taken with percentages of 0.5%, 1%, 1.5, 1.5%, 2%, 2.5%, 3%, 3.5%, 4%, 4.5%, and 5 % to see the effect on the unconfined compressive strength value UCS (Unconfined Compressive Strength). The results showed that the unconfined compressive strength increased by 25%.

The study that examined the effect of eggshell powder (ESP) as a substitute for lime (L) in the stabilization of clay soil (C) had been carried out. The variations of the mixture of eggshell powder, lime, and clay are C+4L, C+3.5L+0.5ESP, C+3L+1ESP, C+2.5L+1.5ESP, C+2L+2ESP. The results showed that the maximum value in the UCS test reached at compressive strength value of 0.92 kg/cm^2 for the mixture variation of C+3L+1ESP, this increased from the original soil UCS value 0.45 kg/cm^2 [9].

The effect of a mixture of eggshell powder on fine-grained soil to unconfined compressive strength had been examined [1]. The results of the unconfined compressive strength test with the addition of 5%, 10%, 15%, and 20% of eggshell powder showed that the highest unconfined compressive strength (UCS) value was obtained with the addition of 10% ESP with a value of 440.02 kN/m^2.

2. Research Methodology

2.1 Research Stages

The research was carried out by taking samples from Cibingbin Village, Kec. Cibaliung, Pandeglang Regency. Soil samples used for unconfined compressive strength testing in the laboratory were made from a total of 48 samples based on variations in the percentage of eggshell powder and the number of days of curing, 0 days and 3 days. Variations in the percentage of eggshell powder consist of 0%, 2%, 4%, 6%, 8%, 10%, 12%, and 14%, with respective curing times of 0 days and 3 days.

The sample was made using a standard compaction test results to obtain the optimum water content and maximum dry density of the sample. The composition of water content soil sample for UCS test is based on standard proctor or compaction test results. Soil property tests are carried out such as analysis of grain size, specific gravity, water content, bulk density, liquid limit, plastic limit, and plasticity index to obtain specifications and classification of the original soil. The results of the unconfined compression test and soil properties were then analyzed to see the effect of adding eggshell powder on the unconfined compressive strength (UCS) value of soil and changes in the soil property index. All the laboratory testing methods using Indonesian National Standard (SNI) [10-17].

2.2 Research Location

Road conditions in Cibingbin Village, Pandeglang Regency Banten, experienced damage due to the load of traffic passing through it. Based on the DCP (Dutch Cone penetration) test, the amount of CBR in the soil in the road area is still below the road base soil requirements. Figure 1 shows road conditions in the area. Based on these conditions, the soil in this area was sampled in this research to carry out soil stabilization efforts by adding eggshell powder as an additive material.

Figure 1. Research location Desa Cibingbin Pandeglang

2.3. Eggshell Powder Processing Process

Eggshell powder can be obtained by taking eggshell raw materials from business places such as martabak shops, restaurants, cake shops and others that produce eggshell waste. The raw materials of collected eggshells are cleaned and dried, then crushed and ground to become powder. The refinement results are then filtered with sieve no. 200. The powder used as an additive is granules that pass sieve no. 200 as shown in Figure 2.

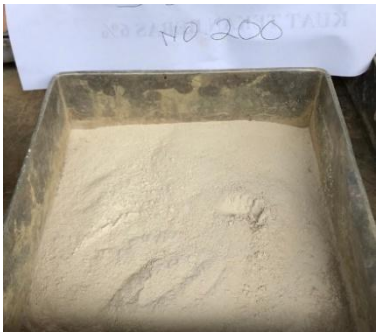

Figure 2. Eggshell powder

3. Results and Discussions

Soil source at the research location were cleaned of organic and non-organic waste to a depth of 10 cm from the surface. Soil was taken to a depth of 50 cm from the ground surface. Soil samples are then tested in the laboratory to obtain several properties parameter. Figure 4 shows examples of soil samples from the site location.

3.1 Physical Properties Tests of Original Soil

The physical properties test of the original soil consists of soil water content test, specific gravity, bulk density, liquid limit, plastic limit, grain size analysis, standard compaction, and unconfined compressive strength test [18]. Where each test is carried out in based on standard using the SNI procedures for each test. Table 1 shows the soil property test results of the original soil samples.

Figure 3. Soil sample taken from site.

Table 1. Laboratory test results of soil physical properties

No	Type of Testing	Result
1	Water content (w)	27.86%
2	Specific gravity (Gs)	2.701

No	Type of Testing	Result
3	volume weight	1.418 gr/cm^3
4	Liquid limit (LL)	65.50%
5	plastic limit (PL)	27.65%
6	plasticity index (PI)	37.85%
7	Passed filter No. 200 (<0,075 mm)	52%

Based on the physical properties test of the soil, it was obtained that the original soil had a water content of 27.86%, a specific gravity of 2.7, and a soil density of 1,418 gr/cm^3. The results of the Atterberg limit tests show that the soil liquid limit is 65.5%, the soil plastic limit is 27.3%, then the plasticity index is 38.2%. Based on the results of the sieve analysis, the percentage of soil passing sieve no. 200 is 52%. Therefore, the original soil can be categorized as clay soil with high plasticity [19-20]. Using soil classification based on the USCS system, it showed that the original soil can be categorized as CH (high plasticity inorganic clay) [20]. Figure 3 shows soil classification graph based on sieve analysis results, water content values and plasticity index values.

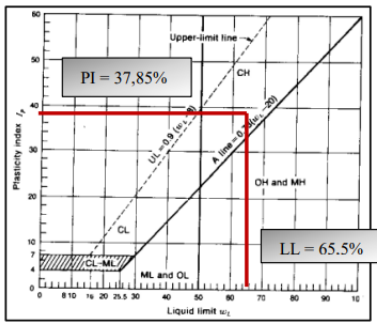

Figure 4. Soil classification graph based on USCS.

3.2 Physical Properties Tests of Mixed Soil

The original soil is mixed with added eggshell powder based on the specified variations of percentage ESP 0%, 2%, 4%, 6%, 10%, 12%, and 14%. All samples then were tested to obtain for physical properties indexes or parameters. The results of the Atterberg limit test for the soil mixture can be seen in Table 2 for the liquid limit, Table 3 for the plastic limit and Table 4 for the plasticity index.

Table 2. Liquid limit test results of soil mixed with ESP.

No	Variations	Liquid limit (LL) (%)
1	Original soil	65.5
2	soil + 2% ESP	65
3	Soil + 4% ESP	64
4	Soil + 6% ESP	63
5	Soil + 8% ESP	62
6	Soil + 10% ESP	60.5
7	Soil + 12% ESP	60
8	Soil + 14% ESP	59

The addition of eggshell powder can reduce the liquid limit (LL) value in each variation, the lowest value is obtained at the 14% variation with a liquid limit (LL) of 59%. It can be included as high plasticity soil because of the liquid limit value is >50% [20]. The plastic limit value of the soil mixture based on variations in the percentage of added ingredients is presented in Table 3.

Table 3. Plastic limit test results of soil mixed with ESP.

No	Variation of mixtures	Plastic Limit (PL) (%)
1	Original soil	27.30
2	soil + 2% ESP	27.78
3	Soil + 4% ESP	28.57
4	Soil + 6% ESP	29.53
5	Soil + 8% ESP	30.78

No	Variation of mixtures	Plastic Limit (PL) (%)
6	Soil + 10% ESP	31.12
7	Soil + 12% ESP	31.58
8	Soil + 14% ESP	32.04

The plastic limit (PL) value increased as the percentages of ESP increased. The highest plastic limit value was obtained at a 14% variation of 32.04%, while plastic limit value of the original soil is 27.30%. It can be concluded that the addition of eggshell powder can increase the plastic limit value. The plasticity index (IP) value for each soil mixture based on variations in the percentage of added ingredients ESP is presented in Table 4. The plasticity index (PI) has decreased but is not significant because the PI value is still in the high plasticity category [20-21].

Table 4. Plasticity index of soil based on variation of ESP.

No	Variations	Plasticity Index (IP) (%)
1	Original soil	38.20
2	soil + 2% ESP	37.22
3	Soil + 4% ESP	35.43
4	Soil + 6% ESP	33.47
5	Soil + 8% ESP	31.22
6	Soil + 10% ESP	29.38
7	Soil + 12% ESP	28.42
8	Soil + 14% ESP	26.96

The addition of eggshell powder can reduce the plasticity index value with a maximum decrease of only 11.24% from the original condition. The condition of clay soil without mixture has a high plastic index value of 38.27% decreases to 26.96% with the addition of 14% eggshell powder. The lowest plasticity index value in the soil mixture with added eggshell powder is 14%, where according to [20] the soil that has high plasticity and cohesiveness makes the soil unstable and is categorized as high with a PI > 17%. Based on this, the addition of eggshell powder to the soil in this study did not have a significant effect on changes in the plasticity index value.

3.2.1. Specific Gravity of Soil

Specific gravity testing with added materials for each variation is carried out to determine zero air void (ZAV) in the compaction test. Table 5 shows the results of the soil specific gravity test along with the soil type classification for each mixture variation.

Table 5. Specific Gravity test results of soil based on variation of ESP.

No	Variations (%)	Specific Gravity	Soil Type
1	0	2.701	Inorganic clay
2	2	2.725	Inorganic clay
3	4	2.726	Inorganic clay
4	6	2.727	Inorganic clay
5	8	2.734	Inorganic clay
6	10	2.745	Inorganic clay
7	12	2.756	Inorganic clay
8	14	2.765	Inorganic clay

The changes in specific gravity values based on variations in the soil mixture is given in Figure 5. The specific gravity of the mixed soil increases with increasing percentages of added eggshell powder. The higher the percentage, the greater the specific gravity value for clay soil, indicating an increase in the mass of the mixed material.

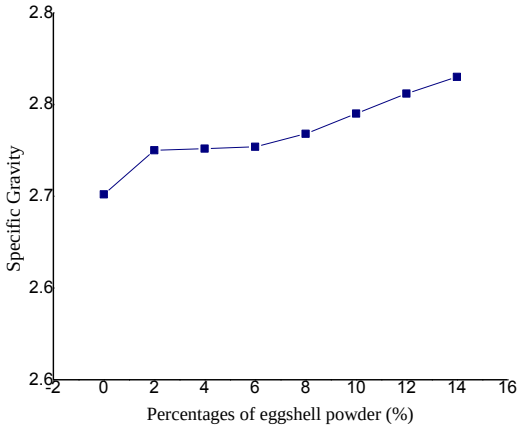

Figure 5. **Specific gravity of soil based on variations.**

Based on Figure 5, it can be concluded that the specific gravity value increases with each variation from the original soil specific gravity value of 2.701 to 2.765 maximum for a soil mixture of 14% eggshell powder. The soil type in each variation of soil mixture with eggshell powder is inorganic clay.

3.2.2. Soil Compaction Test Results

The compaction test is carried out to determine the optimum water content and maximum dry unit weight for each mixture variation which will be used to make composition of soil, water, and ESP material of unconfined compressive strength test samples. Table 6 presents the results of the compaction test for the optimum water content and maximum dry weight for each variation in the percentage of eggshell powder mixture.

Based on the results of standard compaction tests of soil mixtures, it can be concluded that the optimum water content (owc) value increased with variation of 0%, 2%, 4%, 6%, 8%, 10%, 12%, and 14% with owc values of 26%, 26.5%, 27%, 27.2%, 27.5%, 28%, 28.5%, and 29% respectively. The maximum dry weight value decreased from an initial value of 1.425 gr/cm^3 to 1.38 gr/cm^3 at a variation of 14% ESP. By increasing the percentage of eggshell powder content, the optimum water content required for the mixed soil increases. To achieve maximum compaction, adding the percentage of mixed ingredients in the soil increases the volume of the soil.

Tabel 6. Compaction test results of soil mixed with ESP.

Variations	Parameter	3
0%	OMC (%)	26.00
	pd (gr/cm3)	1.425
2%	OMC (%)	26.50
	pd (gr/cm3)	1.406
4%	OMC (%)	27.00
	pd (gr/cm3)	1.400
6%	OMC (%)	27.20
	pd (gr/cm3)	1.393
8%	OMC (%)	27.50
	pd (gr/cm3)	1.391
10%	OMC (%)	28.00
	pd (gr/cm3)	1.389
12%	OMC (%)	28.50
	pd (gr/cm3)	1.385
14%	OMC (%)	29.00
	pd (gr/cm3)	1.38

3.2.3. Unconfined Compression strength (UCS) Tests

The unconfined compressive strength test of soil with added eggshell powder was carried out three tests time for each variation. This procedure was carried out to increase the accuracy of the test according to the codes of SNI 3638:2012 [18]. Determination of soil weight is determined by calculating the mold volume multiplied by the dry weight of the soil compaction test results. Table 7 shows the recapitulation result of the unconfined compression test based on variations in the soil mixture with eggshell powder.

Table 7. Unconfined Compression Strength (UCS) Test Results

Curing time (days)	Eggshell Powder (%)	UCS kg/cm^2
0	0	1.6
	2	1.85
	4	2.022
	6	2.264
	8	2.556
	10	2.605
	12	2.851
	14	2.506
3	0	2.111
	2	2.282
	4	2.472
	6	2.647
	8	2.853
	10	2.966
	12	3.386
	14	3.173

Based on Table 7 and Figure 6, the highest unconfined compressive strength value was obtained at 3,386 kg/cm^2 with variations of eggshell powder content at 12% with curing time on 3 days, the unconfined compressive strength value on 3 days of curing was higher than without curing (0 days) which is 2.851 kg /cm^2. The increase in the unconfined compression strength value can be caused by the formation of calcium silicate hydrate from the reaction of calcium carbonate in eggshells with soil and water. The subsequent decrease of UCS value of 14% of ESP content could be caused by the excess eggshell powder which caused the bond between the soil and the calcium silicate hydrate compound to weaken which had a negative impact on the cohesive properties of the soil [8].

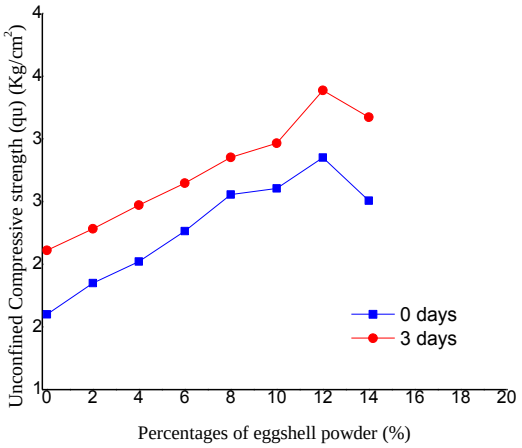

Figure 6. Unconfined Compressive Strength Values (qu) Based on Variations of Egg shell Powder

3.3. Comparisons with Previous Research

Based on the results of this research, it can be concluded that the higher the addition of eggshell powder, the higher the unconfined compressive strength value, where the optimum unconfined compressive strength value is obtained at a percentage of 12% eggshell powder content to the weight of the soil. At the highest percentage of the ESP, 14%, the strength of the soil decreased. Figure 6 shows a comparison of the results of this research with several previous studies. The position of the unconfined compressive strength value resulted in this research when compared with previous research is above the results from [8] and below [1] regardless of the differences in the percentage variations in ESP used.

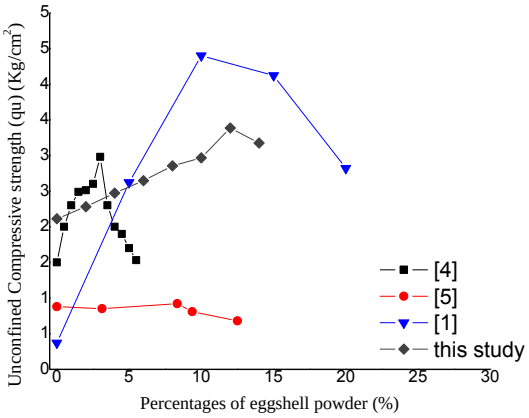

Figure 7. Comparison results with the previous Studies

The optimum unconfined compressive strength value from this research was achieved at 3.386 kg/cm2 for a 12% ESP variation. Research from [8] showed that the optimum unconfined compressive strength value was achieved at 2.98 kg/cm^2 for a 3% ESP variation. The research results [9] showed that the optimum unconfined compressive strength value was achieved at 0.92 kg/cm^2 for the composition variation (Clay+3Lime+1ESP) or 8.33% of ESP, while the research [1] obtained the optimum unconfined compressive strength value of 4.4 kg/cm^2 for 10% ESP variation.

Soil consistency is the ability of the soil to maintain its initial shape from collapse. The optimum qu value of soil mixed with 12% eggshell powder with 0 and 3 days of curing in the research was obtained to be 2.851 kg/cm^2 and 3.386 kg/cm^2 respectively, these results can be categorized as clay soil with a very stiff consistency based on Table 8 [22].

Table 8. Soil consistency based on UCS value.

Soil Consistency	qu (kN/m2)	qu (kg/cm2)
Hard Clay	>400	> 4
Very Stiff Clay	200 – 400	2 – 4
Stiff Clay	100 – 200	1 – 2
Medium Stiff Clay	50 – 100	0,5 – 1
Soft Clay	25 – 50	0,25 – 0,5
Very Soft Clay	< 25	0,25

Based on the plasticity index (PI) value, the requirements for soil base of road are given in Table 9 according to the Indonesian highway regulations from Bina Marga. Three categories of soil base layer are given with PI that must be met the requirements.

Tabel 9. Plasticity Index (PI) requirement for Road

No	Material	PI
1	Subgrade	<15%
2	Subbase	<10%
3	Base Course	<4%

The requirements for highway subgrade must have a PI value of <15%, whereas in this study the lowest PI was achieved at 26.96%. The addition of eggshell powder for soil stabilization based on the PI value in this study is still not optimal because with this plasticity index value the soil is still in the high plasticity category and does not meet the requirements for subgrade soil. Soil with a high PI value will very easily develop soil shrinkage, which can cause instability in the soil.

4. Conclusion

Based on the analysis of test results and discussion, it can be concluded as follows:

1. Based on the USCS system of soil types and classification in this study, the soil can be categorized as inorganic clays with high plasticity (CH). The original soil plasticity index (PI) value was 38.20%.
2. Based on the results of the unconfined compressive strength (UCS) test, the UCS value of the original soil was obtained 1.6 kg/cm^2, the UCS value increased after the soil was mixed with eggshell powder (ESP) based on its optimum water content. The optimum value of compressive strength was 3.386 kg/cm^2, obtained from the 12% ESP mixture variation with 3 days of curing.
3. The addition of ESP can reduce the plasticity index value of the original soil but not significant. The maximum decrease occurred at the added of ESP of 14%. The decrease changes from original soil PI 38.20% to 26.96%. The PI value of mixed soil is still in the category of high plasticity soil.
4. Based on the unconfined compressive strength value, adding the eggshell powder into clay soil can significantly increase the compressive strength of the soil and fulfill the requirements as a good road subgrade, however based on the plasticity index value, the Eggshell powder additives have not had a significant effect in reducing the plasticity properties of clay soil, and does not meet the requirements for a good road subgrade based on regulations for roads in Indonesia.

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