Effect of Curing Period and Binder Quantity on The Characteristics of Bagasse Ash-Calcium Carbide Residue Stabilized Organic Clay

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Abstract. Organic clay has low bearing capacity, low shear strength, sensitive to water content, and high compressibility. Therefore, the study about engineering properties improvement of organic clay is continuously in progress. In this research, bagasse ash (BA) and calcium carbide residue (CCR) were used as stabilizing agents to improve engineering properties of organic clay. Preliminary investigation was done to get the physical parameters, especially Atterberg limit of soil samples. To get the optimum water content (OMC), the original soil was compacted according to standard compaction test. The oven dried soil was mixed with 5, 10, 15, 20, 25 and 30% of binder and cured with 7,21,36 and 56 days curing period. Then, Atterberg limits, unconfined compression strength, and modulus of elasticity of treated soil were investigated. The plasticity index (PI) of stabilized soil decreases proportional to the binder quantity. However, after 10% binder, there was no significant improvement of PI of treated soil. With respect to curing period, PI of stabilized soil decreased, but the decrease of PI was almost constant from 36 to 56 days curing time. Unconfined compression strength (UCS) and modulus of elasticity of stabilized organic clay improve proportionally to both binder proportion and curing period. However, the improvement is not significant enough due to organic content in the organic clay.

1. Introduction
In the last two decades, the application of soft clay stabilization with cement as stabilizing agents on highway and reclamation project is very popular and has been done by many researchers [1-6]. Soft clay that usually has poor volume stability, low shear strength, low bearing capacity, high
Compressibility is widespread all over the world especially in the beach area. In many cities, there are also soft clay deposits up to the depth more than 5.00 meters [7], therefore there are some problems in building infrastructure such as high-rise building, highway, bridges built in some big cities. To overcome the problems, the research about improvement of engineering properties of soft clay is intensively performed and continuously in progress. Recently, chemical stabilization is preferable.

Chemical stabilization is more popular, effective and applicable compared to the other soil improvement technology [8,9]. Cement and lime soil stabilization are very popular in the world. In Asia, however, the use of cement as stabilizing agent is more popular and effective compared to the use of lime [11-14]. Moreover, the use of cement as admixture is very simple and applicable in the site. Some laboratory experiment to study cement stabilized soil have been done [15-20]. Some of those researches accommodate cement proportion in the blend [21, 22]. The research [23] considered the water content for cement stabilized soil. However, very few of the research that specifically took into account the effect of curing period and cement proportion to the characteristics of organic clay. Therefore, the objective of this study is to investigate the effect of curing time and admixture proportion on plasticity index, unconfined compression strength and modulus of elasticity of BA-CCR stabilized organic clay.

2. Experimentals

2.1. Soil

Soil sample was taken from Wonogiri, the province of Mid Java. The method of soil sampling was by boring the soil deposit up to the depth of 10 meters. The bore machine is Rotary Spindle Type Skid mounted with bore diameter is 7.295 mm. The capacity of the machine is 60 meters. Clay deposits was found from -2.00 to –8.00. Then the physical and mechanical properties of the soil sample was investigated in the laboratory according to ASTM test methods as follows: the water content [24], specific gravity [25], Atterberg Limits [26], standard compaction test [27], and unconfined compression test [28]. The result of physical characteristics of soil sample is shown in table 1.

| Physical Characteristics | Result |
|--------------------------|--------|
| Spec. Gravity (G):Reg/OD  | 2.63/2.46 |
| Unit weight, $\gamma$ (gr/cc) | 1.37 |
| Natural water content, $\omega$ (%) | 29 |
| Diameter finer No. 40 (%) | 99 |
| Diameter finer #. 200 (%) | 67 |
| Liquid Limit (%):Reg/OD | 55/35 |
| Plastic Limit ($PL$) | 31 |
| Plasticity Index ($PI$) | 24 |
| Opt. Moisture Content (OMC), % | 33 |
| Max. Dry Density (MDD), gr/cc | 1.56 |
| Unc. Compression Strength (kPa) | 56.2 |
Because the particle size of the soil less than 0.075 mm is 67% > 50%, soil sample is classified as fine grain soil. It is dominated by clay fraction (40%), so the soil is categorized as clay rather than silt. Ratio between oven dried specific gravity and the regular one is less than 1, and the ratio between oven dried liquid limit and regular liquid limit is less than 75%, the soil is classified as organic soil clay (O). Moreover, the regular liquid limit is more than 50%, according to [29] the soil sample is classified as high plasticity organic clay (OH). According to the toughness, the soil sample is categorized as medium toughness, because when the plastic limit test was done to the soil there is no high effort to form the soil. The organic clay is called as high toughness, when there is extra effort to form the soil to be tested on its plastic limit. Based on the standard compaction test [27], it was obtained that the optimum moisture content (OMC) is 33%, and the maximum dry density (MDD) of the soil is 1.56 gr/cc. In addition, the unconfined compression strength of original soil is found 56.2 kPa, that is considered as soft clay.

2.2. The Admixtures

The admixtures used in this research are calcium carbide residue (CCR), and bagasse ash (BA). The CCR was taken from acetylene gas production, it has high content of calcium in the form of active lime (CaO). Whereas the bagasse ash was taken from Madukismo Sugar Factory, Bantul, the province of special region of Yogyakarta, Indonesia. To get the higher content of pozzolanic materials, the original BA was burned to 100°C. In this condition, the pozzolanic compound $SiO_2 + Al_2O_3 + Fe_2O_3 = 68.20\%$ (table 2), it is equivalent to class C fly ash [30]. However, its CaO content is quite low 17.54% that is less than 20%, then calcium carbide was added to improve active lime (CaO) quantity. The gel generated from the reaction between active lime in the calcium carbide and pozzolanic material in the bagasse improves shear strength and bearing capacity of organic clay.

| Table 2. Chemical content of CCR and BA |
|-----------------------------------------|
| Chemical Component | CCR (%) | BA (%) |
| SiO₂ | 8.06 | 40.28 |
| Al₂O₃ | 1.45 | 15.15 |
| Fe₂O₃ | 0.91 | 12.77 |
| $SiO_2 + Al_2O_3 + Fe_2O_3 = 68.20\%$ |
| CaO | 75.78 | 17.54 |
| Na₂O | 0.16 | -- |
| K₂O | 0.67 | -- |
| MgO | 2.98 | -- |
| LOI | 0.16 | 0.21 |
The proportion of bagasse ash is 40%, and 60% for calcium carbide residue [31]. In this research, there was significant decrement of plasticity index, improvement of soil toughness, improvement of CBR, and improvement of unconfined compression strength of clay.

2.3. Test Procedure
To get the high pozzolanic compound \((SiO_2 + Al_2O_3 + Fe_2O_3)\), the original bagasse ash taken from the site was burned to 300°C. The pozzolanic composition on this temperature is 68.20% that is equivalent to class C fly ash. The CCR was dried in the oven and sieve with mechanical sieve according to [32]. The CCR that is passes through the #200 sieve \((d < 0.075 \text{ mm})\) is used as admixture. After that, 2 kg bagasse ash and 3 kg CCR was mixed in the dry condition. This composition is equivalent to \((40\% \text{ BA} + 60\% \text{ CCR})\). The 5, 10, 15, 20, 25 and 30% admixture is then mixed with oven dried organic clay. For example, to get 1 kg treated soil sample with 10% admixture, there was mixed 0.1 kg admixture and 1 kg of organic clay. To investigate the changes of PI with respect to admixture proportion and curing time, each variation was cured in 7, 21, 36 and 56 days curing period to wait cation exchange and pozzolanic reactions occurred. Then, the PI of each variation for every corresponding curing time was investigated according to [26]. Finally, unconfined compression tests were performed according to ASTM standard methods [28].

3. Results and Discussion
3.1. Plasticity Index
The liquid limit (LL), plastic limit (PL) experiment was done to obtain plasticity index (PI) treated soil with 5, 10, 15, 20, 25 and 30% admixtures. The stabilized soil samples were cured on 7, 21, 36 and 56 days curing period. Table 3 shows the results of the test. The test for original soil has been done with the result shown in table 1. Liquid limit, plastic limit, and plasticity index are 55%, 31% and 24% respectively. Figure 1 and 2 present the results of the tests.

With respect to binder quantity, without curing time \((0 \text{ days})\), there is no improvement of plasticity index \((\text{PI})\). It is up and down on the range of 31% and 30%. At 5% binder content, PI decreases from 31% without curing to 25.5% for 56 days curing period. There is significant improvement of PI at 10% binder proportion. It decreases from 31 without curing to 21% on 56 days curing time. However, after 10% binder proportion, the decrease of PI is not significant enough compared to that on 10% binder quantity. For example, at 15% binder, the PI of treated soil increases only from 31% without curing to 20% on 56 days curing period. Similarly, for 30% binder, PI decreases from 30% without curing to 19% on 56 days of curing. This result indicates that the fixation point is on 10% admixture proportion. The reduction of plasticity index, improves the toughness and decreases ductility treated organic clay.
Figure 1. Relation between Plasticity Index and Binder Quantity

This phenomenon occurs because of cation changing reactions, in which, the cation Ca\(^{2+}\) in the CCR changes to K\(^{+}\) or Na\(^{+}\) in the organic soil. Due to this reaction there is flocculation-agglomeration process that decreases the plasticity index, improves the toughness and rigidity of organic clay. In addition, there is a relation between plasticity index and unconfined compression strength [33]. If the plasticity index of the soil decrease, there is improvement of unconfined compression strength, or vice versa.

Figure 2. Relation between Plasticity Index and Curing Time
With respect to curing time, the plasticity index of stabilized soil decreases. At the 15% admixture content, for example, there is a plasticity index of 28% without curing time (0 days) decreases to 22% at 21 days curing period. The PI is continuously decrease up to 56 days curing time. This result says that there is no optimum curing period. This finding is similar to the result of previous research [34] that stated the more curing period, the stiffness of soil improves continuously.

3.2. Unconfined Compression Strength

3.2.1. Unconfined compression tests for Original Soil. Unconfined compression tests were performed to get unconfined compression strength (UCS) for both original soil and bagasse ash-calcium carbide residue organic clay. The UCS of original soil is 56.2 kPa, $\sigma_{50}$ is 24 and $\varepsilon_{50}$ is 0.017. Then modulus elasticity of original soil $E_{50} = 24/0.017 = 1411.76$ kPa. Based on the values of unconfined compression strength and modulus elasticity, the soil sample is classified as soft organic clay.

3.2.2. The Effect of Binder Proportion. Unconfined compression test was done for treated soil with 5, 10, 15, 20, 25, 30% binder proportion and 7, 21, 36, 56 curing time. The result of the test is presented on figure 3. The improvement of unconfined compression strength is proportional to the increase of admixture content. The significant improvement occur on the sample cured on 56 days. Unconfined compression strength improve from 65 kPa to 115 kPa on 10% binder content, and to 142 kPa on 20% admixture proportion, then there is almost no improvement for 25 and 30% binder quantity.

[Figure 3. The Effect of Binder Quantity on Unc. Compr. Strength]
The improvement is more than 200% due to pozzolanic reaction between stabilizing agents and organic clay. This result, however, different from previous research [35]. This research stated that there is no dramatic increase of UCS on polymer stabilized organic clay.

3.2.3. The Effect of Curing Time. Figure 4 presents the relationship between unconfined compression strength (UCS) and curing period. The improvement of UCS is inherent with the increase of curing period. However, the UCS without curing time (0 days) indicates that there is almost no improvement. The UCS of treated soil on 0 days curing time is remain constant, because both cation exchanges and pozzolanic reactions required time to occur. On 36 days curing time, on the other hand, there is significant improvement of UCS. The UCS improves from 56 kPa without curing 116 kPa on 36 days curing time, and to 142 kPa on 56 days curing period.

The significant improvement on 36 days and 56 days curing time, basically is due to the formation of gel as a result of first step and second step pozzolanic reactions. The first step of pozzolanic reaction is the formation of calcium silicate hydrate (CSH) or aluminum silicate hydrate (CAH). Those gels change the engineering properties of organic clay that result on the improvement of shear strength. The second step of pozzolanic reaction is the formation of calcium aluminum silicate hydrate (CSAH) in the form of gel. CSAH is stronger than CSH or CAH, therefore on long period of curing the UCS of stabilized soil improve dramatically.

3.3. Modulus of Elasticity
3.3.1. The Effect of Binder Quantity. Figure 5 is presentation of stress-strain relationship of stabilized clay with 56 days curing times. It can be used to determine the value of modulus elasticity of treated soil with 5, 10, 15, 20, 25, and 30% binder proportion. The value of modulus of elasticity (E50) could be calculated with σ50/ε50. Modulus of elasticity of original soil is found
2,076.67 kPa that is classified as soft clay. The modulus of elasticity increases with respect to binder quantity. For example, it improves to 3,214.3 kPa on 5% admixture, and to 13,750 kPa on 30% binder. This finding is similar to previous research [35] indicated that modulus of elasticity of polymer treated sandy clay soil sample improved significantly with respect to admixture quantity.

The organic clay used in this research retains the improvement of unconfined compression strength and modulus elasticity due to its organic content. Research about slag and fly ash stabilized clayey soil [36] concluded that organic content influence nucleation and cementation that results on slow improvement of shear strength of treated soil. The study about fly ash stabilized peat [37] stated that there is no interaction between the stabilizing agents and organic content on the stabilized peat.

![Stress-strain relationship for treated soil on 56 days curing time](image)

**Figure 5.** Stress-strain relationship for treated soil on 56 days curing time

3.3.2. Effect of Curing Time. Figure 6 is presentation of stress-strain relationship of stabilized organic clay with 25% binder proportion and on 7, 21, 36 and 56 days curing period. It was derived from unconfined compression test. Modulus of elasticity (E) of the treated soil without curing is 2,081 kPa. It is close to the modulus elasticity of original soil even though there was 25% of binder. Without curing time, there is no reaction occurs in the stabilized soil, then there is no improvement of unconfined compression strength and modulus of elasticity of stabilized soil. In long period of curing, 36 days curing time for example, the modulus of elasticity is 8,947.4 kPa, and 10,546.9 kPa for 56 days curing period. The improvement is almost four time compared to that of stabilized soil without curing time.
Figure 6. Stress-strain relationship for treated soil on 25% binder

The significant improvement of modulus elasticity of treated soil is because of cation exchange reaction, first and second stage of pozzolanic reaction. Cation exchange reaction is reaction between Ca$^{2+}$ in the binder and K$^+$ or Na$^+$ in the soil. It generates the bigger grain size of stabilized or so called as flocculation process, that results on the improvement of internal friction angle. In this stage, shear strength, unconfined compression strength, modulus of elasticity, stiffness of stabilized soil improves. The first stage of pozzolanic reaction is the reaction between calcium in the CCR and silica (SiO$_2$) or aluminum (Al$_2$O$_3$) in the bagasse and in the soil, that generates calcium silicate hydrate (CSH) or aluminum silicate hydrate (CAH). Whereas the second stage of pozzolanic reaction is the formation of calcium aluminum silicate hydrate (CASH). In the last two stages, the stabilized soil is getting stronger and harder, or there is improvement of shear strength and modulus of elasticity of stabilized organic clay.

4. Conclusion

After a series of experimental programs was performed, the following conclusion can be drawn from the research. The soil sample is classified as high plasticity organic clay (OH), it has low content of organic material, low maximum dry density, and low specific gravity. The plasticity index (PI) of stabilized soil reduce due to both binder content and curing time. After 10% of binder proportion, there was no more significant reduction of plasticity index, then 10% was taken as binder fixation point. Reduction of plasticity index is mostly because of the decrease of liquid limit. The unconfined compression strength (UCS) of treated organic clay improves with respect to both binder content and curing time. With respect to binder content, there was improvement the UCS of treated organic clay, and significant improvement occur on 9% binder content, then, 9% of admixture (40% BA + 60% CCR) was taken as optimum admixture content. At the same binder quantity and curing periods, the unconfined compression strength (UCS) of stabilized organic clay increase with respect to curing temperature. The temperature of 25°C was taken as the ambient temperature. The modulus
of elasticity (E) of treated organic clay improves with respect binder quantity, curing time and curing temperature. The optimum binder content was found on 9% stabilizing agents. In general, by using the same stabilizing agents, it was found that the treatment of organic clay is not as good as the stabilization program on an-organic clay.

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