Behavior of bagasse ash-calcium carbide residue stabilized soil with polyester fiber inclusion

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Abstract. Bagasse ash is a non-cohesive waste material having small specific gravity that is relatively smaller than that of normal soil, and it behaves as pozzolanic material. Whereas calcium carbide residue (CCR) is hazardous waste materials containing high calcium. Research about using of bagasse ash and CCR is continually in progress. In this paper, a series of experimental studies was undertaken to study the individual and combined effects of randomly oriented polyester fiber inclusions on bagasse ash-CCR stabilized soil. The first step was carried out compaction test on 7, 14, 21, 28 and 36 days-cured soil- mixed with 8% CCR to get optimum curing period that was found at 28 days. Then, the test of soil + 8% CCR + bagasse ash with proportion of 3, 6, 9 and 12% was performed on unconfined compression test to get the best proportion of bagasse ash. That was found 9%. Finally, compaction, direct shear, and unconfined compression tests were performed on 2% fiber inclusion on bagasse ash- CCR stabilized soil (soil + 8% CCR + 9% bagasse ash). Stiffness and maximum dry density (MDD) of soil increase due to additional of CCR, however, it is not significantly affected by the polyester fiber inclusion. Improvement shear strength of stabilized soil is mostly affected by the increase of cohesion rather than due to improvement of internal friction angle. Ductility of bagasse ash- CCR soil mixture increased because of the present of polyester fiber reinforcement.

1. Introduction

Bagasse ash is a fine residue collected from the burning of bagasse in sugar factory. The production of bagasse ash is growing according to production of sugar. It is a non-cohesive waste material having small specific gravity that is relatively smaller than that of normal soil. When burned, bagasse ash behaves as pozzolanic material [1], and therefore its engineering behavior can be improved by addition of calcium carbide residue (CCR). Some experimental studies on chemical stabilization of bagasse ash had been done. Research of additional bagasse ash to concrete was carried out [2]. The research indicated that additional of bagasse ash improved the strength of concrete with significant values. Equipment to burn the bagasse ash to get the optimum temperature to be the best pozzolanic material was made [1]. The additional of bagasse ash alone to expansive clay was performed on unconfined compression apparatus [3]. Result of the study showed that there was no significant improvement of unconfined compression strength.

CCR is hazardous waste material produced from burning acetylene (C2H2), and it contains high active lime (CaO), then it is considered to be an admixture to improve geotechnical characteristics of expansive soil. It can reduce plasticity index, potential and pressure expansions, and improve shear strength of expansive soil. Many research of using CCR alone or combination of CCR with other pozzolanic material were done [4]-[7], and it is continually in progress.

The study about the combined influence on the behavior of fiber reinforcement and CCR- bagasse ash stabilized soil, so far have not been found yet. The purpose is to investigate the individual and combined effects of randomly oriented fiber inclusions on behavior of bagasse ash-CCR stabilized soil. Bagasse ash was taken from Madukismo Yogyakarta sugar factory, and it was mixed with clay with different proportion.
The geotechnical characteristic of bagasse ash-soil specimen, and bagasse ash-CCR soil specimen containing 2% randomly oriented fiber inclusions was investigated. A set of compaction direct shear and unconfined compression test were carried out on bagasse – ash-CCR soil specimen prepared with 2% polyester fiber.

2. Literature Review

Soil improvement by admixtures such as CCR, cement, lime and others is proven technique to improve soil performance. Study of the effect of CCR on shear strength of expansive clay was carried out [8]. The research showed that the shear strength parameters, especially angle of internal friction (φ) did not significantly improve. Improvement of shear strength was basically due to increasing of cohesion. The research on drained triaxial compression tests to study combined effects of CCR stabilization and randomly oriented fiber inclusion on the behavior of silty sand were performed [9], the result showed that no significant improvement of shear strength stabilized soil. Research about engineering properties of CCR stabilized silt clay was done [10], the result indicated that CCR content required to stabilize was determined by CCR fixation point. This point indicates clay capacity to absorb Ca++ and reacts with Ca (OH) 2. Pozzolanic reaction needs the optimum moisture content due to the moisture content less than OMC is not enough to perform the reaction. The results indicates that CCR stabilized soil has higher shear strength compared to the shear strength of lime stabilized soil due to higher content of pozzolanic material on CCR that is around 12.3%.

Due to no significant improvement of CCR stabilized soil strength, the study of combination CCR and other pozzolanic materials is, than intensively performed. The use of CCR and rice husk ash (RHA) was investigated [11]. Ratio of 50% CCR: 50% RHA resulted on unconfined compressive strength of 15.6 mPa on 28-days curing time; and of 19.1% on 180-days curing time. Based on the research, cementation material CCR and RHA was potentially used for high strength concrete. Research of Micro structure of CCR and ground fly ash (GFA) by using SEM, XRD and FTIR was done [12]. CCR-GFA resulted from calcium silicate hydrate is in the form of Ca5 (SiO4)2(OH) 2, that is also found on FTIR analysis. CS-H was obtained from reaction of SiO2 and Ca (OH) 2 from CCR with chemical reaction similar to pozzolanic reaction. The present of calcium silicate hydrate (CSH) improved compressive strength of pasta. In general, the compressive strength of all samples improved with the addition of curing time, and it was almost constant on 42 days. The use of CCR and fly ash (FA) as concrete admixture was done [13]. Ratio of CCR and ground fly ash (GFA) that was used as an admixture for cement replacement was 30: 70. The result of the research indicated that without cement, the new admixture (the mix of CCR and GFA) resulted on 28.4 and 33.5 MPa on 28 days and 90 days of curing time.

Initial and final setting time, were longer compared to that of normal concrete. In addition, CCR and fly ash can be used as a new admixture for concrete, and decreases the production of cement and environmental pollution. Investigation about possibility of using CCR and FA to improve shear strength of silty-clay was done [7]. Micro-mineral structure was done by scanning electron microscopic (SEM) whereas shear strength was examined by performing unconfined compression test. The result showed that addition of CCR decreases the specific gravity, plasticity-index, maximum dry density (MDD) and optimum moisture content (OMC). The change of shear strength was separated on three zone, that is active, inert and deterioration zone. On active zone, shear strength improves due to increase of CCR for all ratio of CCR: FA. The addition of FA, however, did not significantly improve the shear strength of stabilized soil. Moreover the use of CCR as an admixture is better in engineering, economic and environment point of view. The use of RHA and CCR to improve unconfined compression strength of clay was done [4]. Ratio of CCR: RHA were: 30:70; 50:50, and 70:30%, however, the proposed parameter was split tensile strength. The results indicated that composition of 50 (CCR) : 50 (RHA) resulted on split tensile strength 84% higher than that of unstabilized soil [5].
3. Materials and Methods

3.1. Materials

The bagasse ash was taken from Madukismo Sugar Factory Bantul Special Region of Yogyakarta, Indonesia. It was burned, than blended into the fine residue. The soil is local soil taken from Wates the Special Region of Yogyakarta, Indonesia, and CCR was taken from Sedayu welding company. Table 1 shows chemical content of bagasse ash and CCR, whereas Table 2 indicates characteristics of polyester fiber.

| % Chemical Content | Chemical composition | Madukismo Bagasse Ash | CCR |
|--------------------|----------------------|-----------------------|-----|
| Silica (SiO$_2$)    | 47.60                | 0.23                  |
| Alumina (Al$_2$O$_3$) | 6.19                | 2.21                  |
| Iron (Fe$_2$O$_3$)  | 10.21                | 2.09                  |
| Calcium (CaO)       | 1.56                 | 62.3                  |
| Magnesium (MgO)     | ---                  | 7.98                  |

3.2. Methods of Bagasse Ash soil Mixture Preparation

The following are preparation of all types of specimens. The first, the required amounts of bagasse ash and soil were measured and mixed together in the dry condition. If there were no CCR and fiber were used, the dry bagasse ash-soil mixture was mixed with the required amount of water that relies on optimum water content of bagasse ash – soil mixture. If CCR alone was used for stabilization, the dry bagasse ash-soil mixture was first mixed with CCR then bagasse ash CCR –soil mixture was mixed with water. It was found that the fibers could be mixed with the bagasse ash soil mixture more efficiently in the moist condition compared to on the dry state. Therefore, if fiber reinforcement alone was used, the dry bagasse ash-soil mixture was first mixed with water and then put the fiber. If both CCR and fiber were used for stabilization, a moist bagasse ash – CCR soil mixture was prepared similar to that of the previous one, than mixed with fiber.

3.3. Bagasse Ash-CCR Soil Mixtures
Soil mixed with bagasse ash and CCR was cured on 7, 21, 28 and 36 days curing period. This bagasse ash–soil mixtures were then mixed with 2% fiber. Light compaction or standard Proctor Test were carried out on both the bagasse ash – CCR soil mixture and bagasse ash-CCR soil mixtures with fiber. Specimens at standard Proctor were prepared by static compaction. Moreover, direct shear and Unconfined Compression Tests were performed.

3.4. Fiber Reinforced Bagasse Ash–CCR Soil
The effects of fibers on the geotechnical characteristics of bagasse ash – soil mixtures blended with 2% of fibers was investigated by conducting Standard Proctor, direct shear and unconfined compression tests. The tests were performed according to the ASTM standard as follow: compaction test (ASTM D 698); direct shear test (ASTM D 3080), and ASTM D 2116 for unconfined compression test.

4. Result and Discussion

4.1. Compaction on soil + CCR
From previous study [16], it was found that optimum CCR content is 8%. Then compaction test was carried out on soil + 8% CCR cured at 7, 14, 21, 28 and 36 days. Table 3 is the result of the test.

| Curing Time (days) | 7   | 14  | 21  | 28  | 36  |
|-------------------|-----|-----|-----|-----|-----|
| MDD (gr/cc)       | 15.8| 16.9| 17.6| 18.8| 18.7|
| OMC (%)           | 33  | 34.5| 34  | 34.8| 35  |

The longer curing period, MDD of soil+CCR improves up to 28 days of curing time. From 28 to 36 days, however, there is no more improvement on MDD. Then, 28 days is considered as optimum curing time. On the other hand, OMC of soil + CCR looks inconsistent with respect to curing time. Improvement on 28 days curing period of MDD is due to optimum cation exchange reaction that improves stiffness and compaction of CCR soil mixtures.

4.2. Unconfined Compression Test on Soil + CCR + Bagasse Ash
To get optimum content of bagasse ash on bagasse ash-CCR stabilized soil, it was performed unconfined compression test on soil + 8% CCR + bagasse ash with proportion of 3, 6, 9 and 12%. Curing period of this test was 7, 14, 21, 28 and 36 days. Table 4 indicates the result of the test. This test is also to ensure the best curing time that will be used on the tests on soil- bagasse ash- CCR stabilized soil with fiber inclusion.

At 0% bagasse ash-soil, soil + 8%CCR, there is improvement of unconfined compression strength with respect to curing time. However, the improvement is not significant. The significant improvement occurred on soil + 8%CCR + 9% bagasse ash, it is from 41.1 kPa on 0 day of curing to 345.9 kPa on 28 days curing period. Even though there is improvement of unconfined compression on 36 days of curing, it is not significant. Therefore, it is concluded that the optimum bagasse ash content is 9%, and the best curing time is 28 days the same as that of compaction test. It is consistent with previous research [8] stated that optimum ratio between CCR and bagasse ash to get optimum pozzolanic reaction was 1: 1.12.
Table 4. Results Unconfined Compression Test on bagasse ash-CCR stabilized soil

| Curing period (days) | Proportion of bagasse ash (%) |
|---------------------|-------------------------------|
|                     | 0                             | 3   | 6   | 9   | 12  |
| 0                   | 39.8                          | 40.2| 40.8| 41.1| 41.5|
| 7                   | 41.4                          | 55.6| 67.2| 69.1| 71.3|
| 14                  | 42.2                          | 97.1|104.6|124.7|131.2|
| 21                  | 45.1                          |123.6|145.4|161.2|170.1|
| 28                  | 46.6                          |198.8|305.2|345.9|349.5|
| 36                  | 47.9                          |202.3|308.9|348.9|355.9|

4.3. Compaction Test on bagasse ash-CCR stabilized soil with fiber

Soil symbol on this test is C = CCR content (%), A = bagasse ash proportion (%), for example C8A9 is bagasse ash-CCR stabilized soil with 8% CCR and 9% bagasse ash. Table 5. Shows the compaction test results of bagasse ash – CCR soil mixture with and without fiber reinforcement. The values of MDD and OMC do not significantly change due to the fiber reinforcement. It is almost no improvement of MDD with 2% fiber-reinforcement.

Table 5. Compaction Test Results of Unreinforced and Reinforced Bagasse Ash-CCR soil mixtures

| Composition | MDD (kN/m³) | OMC (%) |
|-------------|-------------|---------|
|             | Without fiber | With fiber | Without fiber | With fiber |
| (C8A0)      | 18.6        | 18.5     | 31.8          | 30.9       |
| (C8A3)      | 18.8        | 18.4     | 31.1          | 31.2       |
| (C8A6)      | 18.8        | 18.2     | 31.6          | 30.3       |
| (C8A9)      | 18.9        | 19.1     | 30.3          | 31.2       |
| (C8A12)     | 18.9        | 18.3     | 32.1          | 30.8       |

This result is slightly different from the trend investigated [15] that both MDD and OMC increase with increase in fiber content in silty sand mixed with polypropylene fibers. It is due to the property of
polypropylene fiber that is water absorbing material. In this research, it was used polyester fiber that is probably not water absorbing material.

4.4. Direct Shear Test on bagasse ash-CCR stabilized soil with fiber

As the compaction test performed that MDD and OMC of the bagasse ash – soil were not significantly affected by fiber reinforcement, the specimens for direct shear test were prepared. The specimens prepared were the same condition with that of compaction test, thus the effect of fiber and or CCR could be seen from the results of direct shear test. The possible effects because of water content and the unit weight are avoided. The direct shear tests were carried out on 63 mm diameter and 25.5 mm height with deformation rate of 20 mm per minute. To get an accurate results, it was used 3 (three) specimens for each combination. The normal stress varies in between 28.4 kPa (28kPa), 41.2 kPa (42 kPa), and 79.7 kPa (80 kPa), at deformation rate of 0.25 mm/minute. The results are given on Fig.1 and 2. Soil without fiber reinforcement reached shear failure at the horizontal displacement in between 1 mm and 2 mm.

![Figure 1. Shear stress vs horizontal displacement.](image)
This result is different from the previous research [17], the similar soil got the shear failure at the horizontal displacement more than 3 mm at the high value of normal stress. It shows that the fiber reinforcement improves soil ductility. The compacted soil sample indicated the usual tendency for dilatation. However, the vertical displacement was significantly higher in the fiber reinforced samples than in the unreinforced ones. The vertical displacement in unreinforced specimens was less than 0.25 mm, and decreased with increase in normal stress. The vertical displacement was generally more than 0.50 mm in fiber-reinforced specimens at all stress level, and at normal stress 28 kPa was around 2 mm. The total stress shear strength parameters obtained from direct shear tests on unreinforced and reinforced bagasse ash – soil mixtures are shown in Table 4. Improvement of cohesion (c) and angle of internal friction (φ) due to reinforcement look consistent. Cohesion tends to significantly increase, however it is not followed by improvement of internal friction angle. Therefore, the increase of soil shear strength is basically due to the improvement of cohesion rather than internal friction. It is interesting to notice that increase of cohesion is due to additional adhesion between polyester fiber and bagasse ash-CCR soil mixtures.

**Table 6. Results of Direct Shear test for unreinforced and reinforced 2% fiber- bagasse ash –CCR soil mixtures**

| Mix design | Without fiber reinforcement | With 2% fiber reinforcement |
|------------|-----------------------------|-----------------------------|
|            | c (kPa) Φ (degree)          | c (kPa) Φ (degree)          |
| C8A6       | 20.46 15.5                  | 55.82 17.3                  |
| C8A9       | 27.84 15.5                  | 57.45 20.2                  |
| C8A12      | 32.84 17.4                  | 64.84 21.6                  |
Fig. 3 shows the trend that improvement of shear stress is due to the increase of cohesion. Relative gain of cohesion is expressed as

\[ c^* = \frac{c_1 - c_0}{c_0} \]  \hspace{1cm} (1)

In which, \( c^* \) = relative gain of \( c \), \( c_0 \), and \( c_1 \) are initial and final cohesion. In term of exponen function:

\[ e^{4.3877} \]  \hspace{1cm} (2)

Correlation coefficient \( R = 0.96 \) is strong enough compared to that of internal friction angle with \( R = 0.33 \). Relative gain of shear stress, in addition, has correlation coefficient \( R = 0.962 \) that is close to that of cohesion. It verifies that improvement of shear stress is strongly influenced by the increase of cohesion.

4.5. Unconfined Compression Test

Unconfined compression test were conducted on cylindrical samples, of MDD and OMC state, prepared by static compaction. The height of sample \( h = 13.65 \) cm; diameter \( d = 6.595 \) mm. To make sure uniform compaction, the entire required quantity material was placed inside the mold. A minimum of four specimens were tested for each soil combination. Fig. 4 indicates the stress-strain curves of unreinforced and reinforced specimens.
Figure 4. Stress-Strain Curves on Unconfined Compression

Shear stress, horizontal displacement, vertical displacement and volume changing are affected by fiber reinforcement. Ductility of bagasse ash – CCR stabilized soil increase due to fiber inclusion. It is showed that failure stress on unreinforced soil is on 2 mm, whereas it is 6 – 10 mm for reinforced bagasse ashCCR stabilized soil. Vertical displacement changes significantly affected by fiber reinforcement. It is 0.3 mm for unreinforced, and 0.6mm for reinforced stabilized soil. It is obvious that improvement of soil ductility is influenced by ductility of polyester fiber.

5. Conclusions
A series of experimental programs has been done to investigate the individual effect, and combined effect of polyester- fiber reinforcement on bagasse ash - CCR stabilized soil, then the following conclusions can be drawn from the study:

[1]. In compaction tests, additional of CCR to the soil improves stiffness and MDD of soil. However polyester fiber reinforcement does not significantly change the value MDD, as well as the value of optimum moisture content.

[2]. Cohesion of soil specimens is significantly affected by fiber reinforcement, than it contributes improvement of shear strength of stabilized soil.

[3]. The increase of angle of internal friction of bagasse ash-CCR stabilized soil is slightly influenced by fiber reinforcement. Then soil shear stress is not significantly affected by the increase of internal friction angle.

[4]. The present of fiber improves ductility of bagasse ash-CCR stabilized soil due to ductility of polyester fiber.

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