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Shear behavior of calcium carbide residue - bagasse ash stabilized expansive soil

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Abstract

Expansive soil is widespread all over the world, also in Indonesia. Its existence results on damage of building structures due to its low strength and high expansion. As a result, improvement of this soil is extensively investigated and continually in progress. Calcium carbide residue (CCR) is a hazardous waste produced from burning acetylene. It contains high CaO, then it is considered to be an admixture to reduce the plasticity index, expansion potential as well as to increase shear and compressive strength of expansive soil. Whereas bagasse ash (BA) is a fine residue collected from the burning of bagasse in sugar factory. This research was undertaken to improve the physical and mechanical behavior of expansive soil stabilized with CCR and BA, and it was done in two steps. The first step was the improvement of the physical and mechanical behavior of expansive clay by adding calcium carbide residue (CCR) to the original soil. The result indicates that at 8% CCR, plasticity index and potential pressure of expansive clay was significantly reduced, and unconfined compressive strength of stabilized soil increased. Then, standard compaction, unconfined compression and direct shear tests were carried out on soil + 8% CCR + bagasse ash (BA). The variation in BA was 0, 3, 6, 9, and 12%, and each specimen was cured on 7, 14, 21, 28 and 36 days of curing time. The study indicates that at 9% of BA and on 28 day-curing time, the MDD and unconfined compressive strength were significantly increased. Moreover, addition of bagasse ash on CCR soil mixture improves soil ductility.

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Keywords: expansive soil; calcium carbide residue; bagasse ash; shear behavior.

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1. Background

Expansive soil is found in many locations in Indonesia, especially in arid areas such as Wonogiri Regency, Gunung Kidul, Purwadadi Regency, and Cikampek. It covers more than 20% of Indonesian area [1]. Its existence results in damage to building, road and bridge structures due to its low shear strength and high volume changing. Therefore, improvement of engineering characteristics of this soil is extensively investigated and continuously in progress. Cement stabilized expansive clay, for example, has been already done by some researchers [2−6]. The results indicated that addition of cement on expansive soil improves shear strength and reduces volume changing. Moreover, stabilization of expansive clay with cement mixed with fly ash, rice husk ash, and bagasse ash was done by [7−9]. The results are similar to the previous research, that is, plasticity index and volume changing decrease, and shear strength of stabilized soil improves. Even though much research about admixtures to stabilized expansive clay has been done, the finding of new materials for admixture is always in progress.

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. Research about using of bagasse ash is continually performed. Bagasse ash is a non-cohesive material having a low specific gravity that is relatively smaller than that of normal soil. When burned, bagasse ash behaves as pozzolanic material, and therefore its engineering behavior can be improved by addition of calcium carbide residue (CCR). It is hazardous waste produced from burning acetylene. It contains high CaO, then it is considered to be an admixture to reduce the plasticity index, expansion potential as well as increase shear and compressive strength of expansive soil.

Studies about the shear strength behavior of calcium carbide residue bagasse ash stabilized soil, so far, have not been found yet. This research was then undertaken to improve the physical and mechanical behavior of expansive soil stabilized with CCR and BA, and it was done in two steps. The first step was the improvement of the physical and mechanical behavior of expansive clay by adding calcium carbide residue (CCR) to the original soil. Then, standard compaction and unconfined compression tests were carried out on soil + 8% CCR + bagasse ash (BA). The variation in BA was 0, 3, 6, 9, and 12%, and each specimen was cured on 7, 14, 21, 28 and 36 days of curing time.

2. Literature review

Chemical stabilization by calcium carbide residue (CCR), cement, fly ash (FA), rice husk ash (RHA), and bagasse ash, or a combination of them, is a proven technique to improve soil performance. Research on undrained compression triaxial test to study the effect of calcium carbide residue on shear strength of expansive clay was carried out by [10]. Observation about the addition of bagasse ash alone to expansive clay was done by [11]. The result indicated that both the compressive and shear strength of expansive clay did not significantly increase. The use of CCR and rice husk ash (RHA) was investigated by [12,13]. A ratio of 50% CCR: 50% RHA resulted in unconfined compressive strength of 15.6 MPa on 28-days curing time and of 19.1 MPa 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 by [14]. CCR-GFA resulted from calcium silicate hydrate (C-S-H) is in the form of $Ca_5(SiO4)_2(OH)_2$, that is also found on FTIR analysis. The C-S-H was obtained from a reaction of SiO2 and Ca(OH)2 from CCR with chemical reaction similar to pozzolanic reaction. The presence of C-S-H improved the compressive strength of pasta. In general, the compressive strength of all specimens improved with the addition of curing time, and it was almost constant at 42 days. The use of CCR and fly ash (FA) as concrete admixture was done by [15]. The 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 in 28.4 and 33.5 mPa on 28 days and 90 days of curing time respectively. Concrete with CCR-GFA admixture has a longer initial and final setting time 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 the possibility of using CCR and FA to improve shear strength of silty-clay was done by [16]. Micro-mineral structure examination was done through SEM whereas shear strength was examined by performing an unconfined compression test. The result showed that the addition of CCR decreases the specific gravity, plasticity-index, MDD and OMC. The changes of shear strength was separated on three zones, namely the active, inert and deterioration zone. On the 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.

Research about the engineering properties of CCR stabilized silty clay was done by [17]. In the research, the CCR content required to stabilize was determined by CCR fixation point that indicates the clay's capacity to absorb Ca++ and react with $Ca(OH)_2$. Pozzolanic reaction needs the optimum moisture content because moisture contents lower than OMC are not enough to perform the reaction. The results indicate that CCR stabilized soil has a higher shear strength compared to the shear strength of lime stabilized soil. This is due to the higher content of pozzolanic material on CCR, which is around 12.3%. Moreover, the use of CCR as an admixture is better from an engineering, economic and environmental point of view. The use of RHA and CCR to improve unconfined compression strength of clay was done by [18]. Similar research was done by [19, 20]. Ratio of CCR : RHA were 30:70; 50:50, and 70:30%; however, the proposed parameter was splitting tensile strength. The results indicated that composition of 50 (CCR) : 50 (RHA) resulted in splitting tensile strength 84% higher than that of unstabilized soil.

3. Research methods

3.1. Property index

The property index experiment used ASTM Standard D 423-66, D 424-74, and D 427-74. In this experiment, soil stabilized samples were prepared as follows: original soil (CCR 0%), soil + CCR 2%, soil + CCR 4%, soil + CCR 6%, soil + CCR 8%, and soil + CCR 10%. Those samples were cured for 7 and 14 days to examine the change of property indices. Table 1 summarizes the samples that were examined.

Table 1. Summary of samples for property indices experiment

CCR content	Curing time (day)		
(%)	0	7	14
0	C0W0	C0W7	C0W14
2	C2W0	C2W7	C2W14
4	C4W0	C4W7	C4W14
6	C6W0	C6W7	C6W14
8	C8W0	C8W7	C8W14
10	C10W0	C10W7	C10W14

CxWy = sample with CCR content of x%, and y days curing time

3.2. Compaction test

The compaction test was undertaken under two conditions. The first was for soil + x% CCR alone with 7, 14, 21, 28 and 36 days curing time, and the second for soil + x% CCR + bagasse ash (3, 6, 9 an 12%) with the same curing time as the previous one. A summary of samples can be seen in Table 2.

3.3. Unconfined compression test

The standard used in this experiment was ASTM D2850-70 and AASHTO T234-70. The purpose of this experiment was to find unconfined compression strength of original and stabilized soil. The CCR content used in this experiment was the one that resulted in the maximum decrease of plasticity index, potential and swelling pressures, as well as activity of original soil (x%). Whereas the content of bagasse ash was 0, 3, 6, 9, and 12% with 7, 14, 21, 28 and 36 days curing time. The summary of samples tested on unconfined compression is the same as that of the compaction test (Table 2).

Table 2. Summary of Compaction samples (CCR = x%)

Curing time (days)	Bagasse Content (%) 0	3	6	9	12
0	W0T0	W0T3	W0T6	W0T9	W0T12
7	W7T0	W7T3	W7T6	W7T9	W7T12
14	W14T0	W14T3	W14T6	W14T9	W14T12
21	W21T0	W21T3	W21T6	W21T9	W21T12
28	W28T0	W28T3	W28T6	W28T9	W28T12
36	W36T0	W36T3	W36T6	W36T9	W36T12

x: CCR content resulting maximum decease of : plasticity index, potential and swelling pressure

WaTb: sample with a day curing time, bagasse ash content b% and X% of CCR

3.4. Direct shear test

The specimens of direct shear test were circular with a diameter of d = 6.30 cm and a thickness of t = 2.55 cm. Two combinations were tested: soil + CCR with 28 days curing time (CxWz), and soil + CCR + bagasse ash (CxAyWz), in which x is the CCR content resulting on maximum decrease of plasticity index, potential and swelling pressure of original soil, y is the bagasse ash content resulting on maximum unconfined compression strength, and z is the curing time of 28 days. The normal stress was 28.4 ; 41.2 and 54 kPa.

4. Results and discussion

4.1. Plasticity index and swelling potential

The results of plasticity index and swelling potential experiment can be seen in Table 3. A maximum decrease of those parameters occurred on 8% CCR content and 7 days curing time (C8C7) due to optimum ion reaction, i.e. Ca+2 and Mg+2 in CCR replace Na+ and K+ on expansive clay. Because of this phenomenon, the soil is siffer. Therefore the plasticity index swelling potential as well as the swelling pressure decrease. The result is in good agreement with the previous study by [21].

Table 3. Result of Plasticity Index and Swelling Potential

		Swelling Potential (%)		Swelling pressure (kPa)	
CCR(%)	I P(%)	[21]	Lab	[21]	Lab
C0W7	47.5	11.2	12.11	298	301
C2W7	41	7.8	10.4	278	286
C4W7	35	4.9	5.3	209	217
C6W7	27.4	3.6	3.9	172	181
C8W7	16.7	1.9	2.3	129	136
C10W7	16.9	0.82	2.4	98	137

4.2. Compaction test

CCR stabilized soil compaction test was done on 8% CCR content and 0, 7, 14, 21, 28 and 36 days curing time. Table 4 is the result of this experiment. Maximum dry density (MDD) improved proportionally to the increase of curing time. On 28 days curing time, the maximum improvement of MDD occurred. This is due to an ion transfer reaction that resulted in flocculation-agglomeration, causing the change of physical and mechanical properties. In addition, on 28 days curing time, pozzolanic reaction, i.e. formation of C-S-H and C-A-H, start to happen then MDD improves significantly.

Table 4. Result of CCR stabilized soil compaction

Curing time (days)	0	7	14	21	28	36
MDD (gr/cc)	14.3	15.2	16.8	17.8	18.5	18.3
OMC (%)	36	34,5	33,5	33	32	31

The CRR- Bagasse ash stabilized soil was done with 8% CCR content, and bagasse ash variation was 0, 3, 6, 9, and 12% with 7, 14, 21, 28 dan 36 days curing time. Table 5 summarizes the result of the experiment. When bagasse ash content increased, OMC decreased proportionally to the improvement of bagasse ash. This is due to bagasse ash being not water absorbing. The MDD, however, improves due to increase of the bagasse ash content. At 6% bagasse ash content, there is significant improvement in MDD, in particular at 28 days curing time. Previous research [6] stated that the optimum ratio of bagasse ash : cement optimum is 3:4, therefore this research which result on ratio 6% bagasse ash : 8% CCR is in good agreement with the previous one.

Table 5.Summary of CCR-bagasse ash stabilized soil compaction

Curing time(days)	Content of bagasse ash (%)									
	0		3		6		9		12	
	γ (kN/m3)	wopt (%)	γ (kN/m3)	wopt (%)	γ (kN/m3)	wopt (%)	γ (kN/m3)	wopt (%)	γ (kN/m3)	wopt (%)
0	14.3	36	14.8	35	15	34	15.4	33	15.5	36
7	15.2	34.5	15.9	34	15.6	33.5	15.9	32	15.9	34.5
14	16.8	33.5	16.9	33	17.1	33	17.3	31.5	17.3	33.5
21	17.8	33	18.1	32	17.9	32.5	17.8	31	17.9	33
28	18.5	32	18.9	31	18.8	31	18.7	30	18.4	32
36	18.6	31	18.9	30	18.8	30.5	19.2	29	19.3	31

4.3. Unconfined compression of CCR- bagasse ash stabilized soil

Unconfined compression experiment of CCR-bagasse ash stabilized soil was performed on MDD and OMC, 8% CCR, and various content of bagasse ash (0, 3, 6, 9 and 12%). The specimen was cylindrical, with a diameter of 6.6 cm and height of 13.7 cm. The soil sample was then statically compacted. To obtain the proposed compaction, the stabilized soil was filled in the cylinder then compacted on three layers. Table 6 shows the result of the experiment.

Table 6. Result of UCS of CCR-bagasse ash stabilized soil

Curing time (days)	Contain of Bagasse Ash (%)				
	0	3	6	9	12
0	40.2	40.9	41	41.8	42.1
7	41.2	58.5	65.3	75.1	76
14	45.3	98.2	108.8	125.9	129.6
21	52.6	156.1	170.4	227.8	235.2
28	72.1	245.6	304.5	337.9	345.9
36	74.2	250	310.8	354.7	368

Improvement of unconfined compression strength with respect to curing time occurs on 0% bagasse ash content; however, it is not significant. It happens significantly on 9% bagasse ash content in which unconfined compression strength without curing time is 41.8 kPa, and it improves markedly on 36 days curing time, that is 354.7 kPa. Similarly, improvement happens on 12% bagasse ash content. However, an improvement of unconfined compression strength from 9% to 12% bagasse ash content is not significant. With respect to curing time, a significant improvement of unconfined compression strength is shown on 21 to 28 days. After 28 days curing time, there is no significant improvement (Fig. 1).

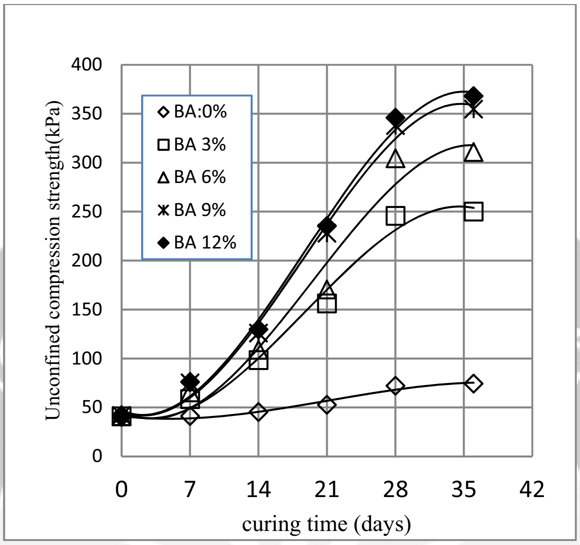

Fig. 1. UCS of CCR- bagasse ash stabilized soil

4.4. Direct shear test

The result of direct shear experiment of CCR-bagasse ash stabilized soil with respect to curing time is given on Table 7. When curing time increases, cohesion improves and internal friction angle decreases. However, there is still improvement of shear stress. Those phenomena occur due to the first pozzolanic reaction in which generates calcium silicate hydrate (C-S-H) and aluminum silicate hydrate (C-A-H) was totally completed, and the second pozzolanic reaction which generates calcium aluminum silicate hydrate C-S-A-H starts to happen.

Table 7. Result of Direct Shear Test

Shear Stress Parameter	C8A9W21	C8A9W28	C8A9W36
Cohesion, c (kPa)	32.15	35.5	36.4
Int. friction angle ,φ(O)	21.20	25.90	27.80

Fig.s 2 and 3 show the variation of shear stress and vertical displacement with shear displacement of CCR stabilized and CCR bagasse ash stabilized soil specimens. The shear stress displacement behavior was influenced markedly by bagasse ash admixture. While soil specimens without bagasse ash reached their failure shear stress at displacement around 2 mm, the corresponding displacement on CCR-bagasse ash stabilized soil specimens were generally greater than 3.5 mm. This is evidence that the addition of bagasse ash improves the ductility.

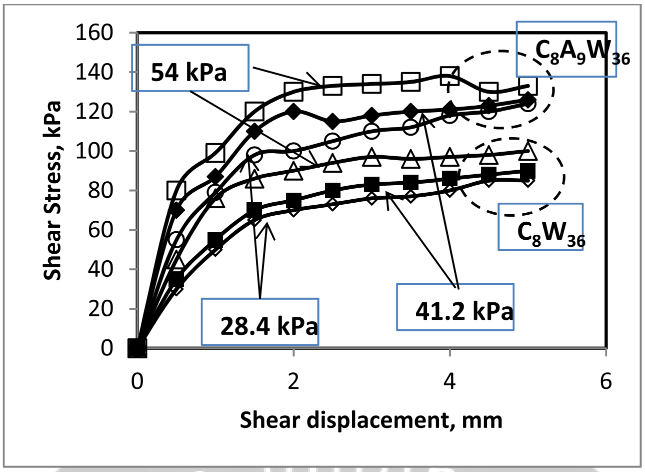

Fig. 2. Shear stress-Shear displacement of C_8W_{36} and C8A9W$_{36}$

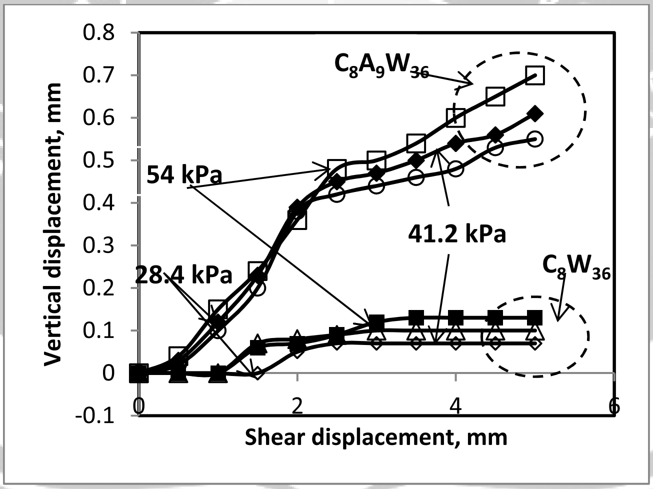

Fig. 3. Vertical displacement-Shear displacement of C_8W_{36} and $C_8A_9W_{36}$

5. Conclusion

An experimental program was performed to investigate the effect of calcium carbide residue (CCR) and bagasse ash on shear strength and other geotechnical characteristics of expansive soil. The experiment was conducted on soil + CCR and soil + CCR + bagasse ash with 7, 14, 21, 28 and 36 days curing time. Conducted experiment were index properties, compaction test, unconfined compression test and direct shear test. The following conclusions are drawn from the study.

- The addition of 8% calcium carbide residue (CCR) significantly decreases the plasticity index, swelling and pressure potential of CCR stabilized soil.
- The CCR stabilized soil compaction test indicates that maximum dry density (MDD) improves proportionally to the increase of curing time, and maximum improvement occurred on 28 days.
- The addition of 6% bagasse ash to CCR-bagasse ash stabilized soil significantly improved MDD, especially on 28 days curing time.

- Significant improvement of unconfined compression strength of CCR-bagasse ash stabilized soil specimens occurred on 9% bagasse ash and 28 days curing time. An increase of unconfined compression strength still occurred on 36 days curing time; however, it was not significant.
- In direct shear tests, the bagasse ash increase the failure displacement and the vertical displacement of CCR stabilized soil compacted on MDD – OMC state. In addition, it increases ductility the behavior of CCR-soil specimens.

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