Influence of bagasse ash, calcium carbide residue and polyester fiber addition on shear strength of organic clay

John Tri Hatmoko¹, Luky Handoko²

¹ Department of Civil Engineering, Universitas Atma Jaya Yogyakarta
Babarsari 44, Yogyakarta, Indonesia
Email : john.trihatmoko@uajy.ac.id

² Department of Civil Engineering, Universitas Atma Jaya Yogyakarta
Babarsari 44, Yogyakarta, Indonesia

Abstract. Organic clay has bad engineering properties. It is compressible, sensitive to the changes of water content; and it has poor bearing capacity and shear strength. Therefore, the research regarding improvement of this soil is intensively performed and continually in progress. In this research, bagasse ash (BA), calcium carbide residue (CCR) and polyester fiber were used to improve the shear strength of organic clay. A set of laboratory experiment were performed to study the effects of BA, CCR and polyester fiber inclusions on the shear strength of organic clay. To obtain optimum moisture content (OMC), standard compaction test was worked out for original soil. The oven dried BA (varied as 10 %wt, 20 %wt and 30 %wt) were mixed with the soil, and water was added to its OMC. Then, 1 to 2 %wt freely oriented polyester fiber was mixed with BA-soil samples. The BA-soil specimen and BA-soil specimen containing polyester fiber was investigated through direct shear tests. Finally, 4 %wt CCR was added to both BA-soil mixtures, and BA-soil mixture with fiber inclusion. The direct shear tests were then carried out on those samples with 14, 28 and 36 days curing period. This research shows that calcium carbide residue increases shear strength of BA-soil samples and BA-soil specimens with fiber inclusion. It shows also that fiber inclusion increases ductility of treated soil. However, the use of BA only does not significantly increase the shear strength of stabilized soil.

Keywords: bagasse ash, calcium carbide residue, organic clay, polyester fiber, shear strength

1. Introduction
Organic clay has unfavorable engineering characteristics. Even though preloading is already applied, the organic clay has still low bearing capacity, low shear strength and high compressibility [1-9]. Therefore, if the building is directly built based on the organic clay there would be excessive settlement, creep and bearing failure. In practice, the organic clay is cut and replaced by materials with better mechanical properties, e.g. crushed stones or well-graded sand. However, there will be expensive project if substitution material is not available near the project site. Then, soil stabilization is considered as good alternative solution.

Chemical improvement of soft clay, e.g. to increase shear strength, bearing capacity, and to decrease compressibility, has been intensively researched. Use of ordinary Portland cement, lime,
fly ash, bagasse ash, calcium carbide or combination of those materials to increase engineering properties of soil with high organic content has been successfully worked out [10-16]. Researches regarding the use of fly ash as the admixture for soft clay stabilization have been also worked out [17-20]. Challenge exists due to limited supply of fly ash in the market which is used for clay stabilization. Application of alternative materials, with similar influence to fly ash, as the admixtures should therefore be considered. In this research, combination of the bagasse ash (BA) and calcium carbide residue (CCR) is used as stabilizing agents to increase engineering properties of organic clay. Polyester fiber, then, was blended to the stabilized soil with free orientation to achieve higher shear strength and ductility of the BA-CCR stabilized organic clay.

The bagasse ash is waste material collected from sugar factory. It is fine residue and non-cohesive material having specific gravity is relatively smaller than that of normal soil [20,21]. It behaves as a pozzolanic material with high proportion of silica (SiO₂), alumina (Al₂O₃), and iron (Fe₂O₃). The addition of bagasse ash as replacement of cement in concrete significantly improves compressive strength [23]. Research regarding stabilization of expansive clay with bagasse ash as admixture was already worked out [24]. There was small improvement of unconfined compression stress, due to lack proportion of lime (CaO) in the bagasse ash. Therefore, the material having high proportion of CaO should have significant increase of the shear strength of soil due to pozzolanic reactions.

Calcium carbide residue (CCR) is hazardous waste material produced from burning acetylene (C₂H₂) and it contains high proportion of active lime (CaO). The CCR soil stabilization is proven technique to improve the engineering performance of soft clay. Research about the effect of CCR alone on the behavior of expansive clay has been performed by many works. The results indicated that the plasticity index, potential pressure, and swelling pressure proportionally decrease to the CCR quantity [25-26]. There was, however, no significant increase of shear strength [27]. The experimental program on drained triaxial compression test to study the combined effects of CCR and radomly oriented fiber of the CCR silty-sand treated soil was done [28]. The results showed that there was not sufficient shear strength increase of stabilized soil. The CCR with or without fiber inclusion does not give significant increase the shear strength of treated soil. For this reason, other material that behaves as a pozzolanic matter is required to significantly improve the shear strength of stabilized soil.

2. Materials and methods

2.1. Materials

2.1.1. Soil sample

| Number | Soil Parameter          | Quantity        |
|--------|-------------------------|-----------------|
| 1      | Water content (w)       | 42.6%wt         |
| 2      | Spec. gravity (G)       | 2.4             |
| 3      | Liquid limit (LL)       | 76.8%           |
| 4      | Plastic limit (PL)      | 53.4%           |
| 5      | Plasticity Index (PI)   | 23.4%           |
| 6      | Max. dry density (MDD)  | 1.49 gr cc⁻¹    |
| 7      | Opt. moisture content (OMC) | 26.9%wt   |
| 8      | Unc. compr. strength (UCS) | 85.9 kPa   |
The original soil sample was taken from Wates, Kulonprogo. It is very poor soil with low CBR and maximum dry density (MDD). Preliminary tests were done for the original soil following ASTM standard (Table 1). The original soil is classified as high plasticity organic soil (OH). As organic soil, its color is black changes to lighter color when it is dried.

2.1.2. Stabilizing agent
The admixtures are BA, CCR and polyester fiber as reinforcement. The BA was from Madukismo Sugar Factory. The BA is burned to 100°C to obtain higher pozzolanic agents (silica, alumina and iron). Total silica, alumina and iron of Madukismo BA is 64.65 %wt which is similar to class C fly ash. However, the calcium content is only 9.25 %wt which is lower than minimum standard value at 20 %wt. It is different from two others fly ashes that are Bukitasam fly ash [15] and Australian fly ash [26] which are categorized as class F fly ashes. Due to less calcium content on the BA, admixtures should have high calcium content to generate pozzolanic reaction.

In this work, calcium carbide residue (CCR) is lime like hazardous waste collected from acetylene gas factory, and it has high content calcium. The chemical content of the CCR are silica (SiO₂ 8.43 %wt), alumina (Al₂O₃ 1.67%wt), iron (Fe₂O₃ 1.08%wt), and active calcium (CaO 78.76%wt), sodium (Na₂O 0.00%wt), potassium(K₂O 0.67%wt), magnesium (MgO 2.98%wt), and lost of ignition (Lol 0.16%wt). Whereas, characteristics of polyester fiber is (diameter = 0.080; spec. gravity = 1.4, and tensile strength = 135 mPa). Additionally, iron oxide and aluminum oxide can be found as by product of metal melting and recycling [30,31] which provides opportunity for future application.

2.2. Methods

2.2.1. BA-soil and BA-soil-polyester fiber mixtures.
For direct shear test, the required admixtures containing of 7 kg original soil, 4 kg BA, and 70 gr polyester fiber (PF) were prepared. Soil and the BA (varied as 10 %wt, 20 %wt and 30 %wt) was mixed on the oven dried condition. Water was then added to the BA-soil mixtures. After that, the blend was put into the PVC pipe with diameter (d) 63 mm and height (h) 80 mm and then compacted according to compaction test standard of ASTM D698-07 [32]. After being compacted, the mixtures were pulled out from the pipe and cut into 3 pieces with d 63 mm and h 26 mm. The sample, was then wrapped with poly-bag, and cured with 7 days curing time. Finally, the direct tests were performed for each sample according to ASTM. The applied normal stresses are 28.4, 41.2, and 54 kPa. Similar attempts were worked out for the BA-soil- polyester fiber mixing. The freely oriented 1 %wt PF were mixed with BA-soil mixtures in dry condition, and compacted in PVC pipe according to compaction standard. Then, the sample were cured and tested on the direct shear apparatus. For standard compaction test, the procedures follow the ASTM standard.

2.2.2. BA-soil – CCR and BA-soil-PF-CCR mixtures.
The test of the BA-Soil – CCR and BA-Soil-PF-CCR mixtures was worked out for 14, 28 and 36 days curing period. The required soil sample was 5.6 kg and app. 0.25 kg for CCR. The CCR was mixed with BA-soil and BA-Soil-PF mixtures in dry condition. After that the test procedure are similar to the previous procedures.

3. Results and Discussion

3.1. Direct shear test of BA-soil mixtures
Addition of bagasse ash to the soil does not increase the cohesion of bagasse ash treated soil. There is limited small increase of cohesion force due to bagasse ash for both the mixture with and without fiber inclusion. For example for 20 %wt of BA, the cohesion of the blend is 92.89 % with-
out fiber and 93.92 % with fiber. The increase is 1.1 % only. With respect to BA content without fiber, the cohesion is 92.89 % for 20%wt BA and 94.08 for 30 %wt BA. There is only 1.3 % increase. Similar condition is shown in the treated soil with fiber inclusion. No significant improvement of cohesion is due to characteristic of the BA that is non cohesive material. Additionally, the friction properties of polyester fiber tends to decrease the cohesion of the blend.

Internal friction angle significantly increases due to fiber inclusion, but there is no increase of internal friction with respect to BA content. For example, for 20 %wt BA content, the internal friction improves from 8.6° without fiber to 12.5° with fiber, i.e. 45.6% increase. Similarly for 30 %wt BA, increase of internal friction angle is 55.5 %. The increase is due to friction properties and high tensile strength of polyester fiber. The result is in a good agreement with the investigation done by Kaniraj and Havanagi [28]. Their study was about influence of fiber on sandy clay, and the results said that the peak friction angle increase from 35° to 46° due to fiber inclusion.

3.2. Direct shear test of BA-CCR – soil mixtures

3.2.1. Cohesion (c).
After 4 %wt CCR was added to BA-soil mixtures with or without fiber inclusion and cured 14, 28 and 36 days, there is no increase of cohesion of treated soil with respect to BA quantity, curing time and fiber inclusion. For example, for 14 days curing time, 20 %wt BA with fiber, cohesion is 93.1 kPa, whereas it is 94.9 kPa for 30 %wt BA. The cation exchange reaction between Ca^{2+} in the CCR and K⁺ or Na⁺ in the soil specimen generates the coarser and stiffer grain on the treated soil [14,15]. It does not increase the cohesion, however it decreases plasticity index (PI) that leads to higher stiffness and shear strength of stabilized soil. Moreover, the BA and polyester fiber are not cohesive materials. Thus, they do not increase the cohesion of the blend.

3.2.2. Internal friction angle (φ).
There is significant increase of internal friction angle (φ) of bagasse ash – CCR soil mixtures with or without fiber inclusion. The increase is basically due to bagasse ash content, 4 %wt CCR, curing time, and fiber inclusion. The coagulation process which is the product of cation exchange reaction occurs during short curing period, i.e. 7 to 14 days. The reaction forms the bigger size of treated soil, therefore it increases internal friction of the blend. With respect to curing period, for 10%wt BA without fiber, the internal friction angle significantly increases from 8.2° for 0 days of curing to 21.3° for 14 days of curing, i.e. the increase is almost triple. From 28 to 36 days curing time, however, there is no significant improvement of φ. For 10 %wt BA without fiber, internal friction is 28.2° for 28 days of curing compared to 29.1° for 36 days of curing. There is only 3.2 %wt increase of φ. With respect to BA content for 14 days of curing, without fiber, the internal friction angle is 9.5° for 20 %wt BA and 12.7° for 30 %wt BA, i.e. increase by 34.7%. The amount of bagasse ash helps the cation exchange reaction between CCR and original soil. Moreover, the friction property of the fiber contributes the improvement of internal friction angle (φ).

3.2.3 Shear strength
Shear strength of soil-BA-CCR with and without fiber inclusion increase significantly because of BA quantity, time curing and fiber inclusion (Figure 1). The presented shear strength is on 100 kPa normal stress. With respect to curing time, for example, 20%wt of BA without fiber the shear strength is 135.8 kPa on 14 days of curing compared to 152.2 kPa for 28 days curing time, increases by 12.1%. Cohesion of the treated soil does not increase shear strength, since there is no significant increase of cohesion of the stabilized soil. Internal friction angle, in contrary, significantly increase shear strength of treated soil.
Addition of 4%wt CCR to BA-soil mixtures generates cation exchange reaction, those are, Ca$^{+2}$ and Mg$^{+2}$ in the CCR replace Na$^+$ and K$^+$ in the soil. The result of this reaction is bigger grain size or widely known as flocculation. Therefore, the internal friction of the mixture significantly increases. During the long period of curing, for example 28 or 36 days, there is reaction between calcium (Ca) in the CCR and silica (SiO$_2$) and alumina (Al$_2$O$_3$) in the BA to generate the gel in the treated soil. This reaction is usually called as pozzolanic reaction. Due to this reaction, the soil becomes stiffer and stronger, i.e. higher shear strength.

The addition of 1 %wt freely oriented fiber inclusion in the soil-BA-CCR mixtures does not significantly increase shear strength. For example, for 20%wt BA and 28 days curing period, the shear strength is 152.2 kPa without fiber compared to 156 kPa with fiber inclusion, i.e. less than 10% increase. The result shows discrepancy from the research made by Parsons and Kneebone [17] where they found that fiber reinforcement increased significantly, both peak and residual strength, when cement was stabilized with sand soil.

3.2.4 Ductility
CCR and bagasse ash (BA) increase soil stiffness or decrease ductility of BA-CCR-soil mixture. However, polyester fiber increases ductility or reduces stiffness of stabilized soil (Figure 2). The shear stress-shear displacement behavior is markedly dependent on the polyester fiber inclusion. For the blend with fiber, the failure shear stress reaches on app. 4 mm displacement. Whereas the shear stresses failures of BA-CCR-soil mixtures without fiber reinforcement shows 1 to 2 mm shear displacement. This result informs that fiber addition increases ductility of BA-CCR-soil in comparison when fiber reinforcement is not applied.

![Figure 1](image-url). Shear strength vs. curing time of stabilized soil of various bagasse ash (BA) content for cases with (W) and without (WT) fiber reinforcement
Figure 2. Shear stress vs. shear displacement of treated soil for cases with (W) and without (WT) fiber reinforcement

4 Conclusions
A set of experimental program was performed to investigate the influence of varied composition of bagasse ash-soil, and bagasse ash- calcium carbide residue – soil mixtures with and without fiber reinforcement. Experiments were worked out on original soil, BA-soil mixtures, BA-CCR-soil mixtures, and freely oriented fiber inclusion to both BA-soil and BA-CCR-soil mixtures. In the standard compaction test on BA-soil mixtures, there are slight increase of compaction parameters, i.e. OMC and MDD, due to polyester fiber inclusion. Bagasse ash and fiber reinforcement resulted in slight increase of cohesion of BA-soil mixtures. Internal friction angle of BA-soil specimen significantly increases due to polyester fiber reinforcement, but there is no improvement of internal friction due to BA content. BA content, curing period, and fiber inclusion do not increase cohesion of BA-CCR-stabilized soil. However, internal friction angle of stabilized soil significantly increases due to BA content, curing period, and polyester fiber reinforcement. The polyester fiber reinforcement increases the ductility or reduces the stiffness of BA-CCR treated soil.

5 Acknowledgement
The authors would like to deliver special thanks to The Ministry of Education and Culture, Republic of Indonesia for the funding of the research through the Fundamental Research of Higher Education Grant. Contribution and support from Research Institute and Public Affairs of Universitas Atma Jaya Yogyakarta is also acknowledged.

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