Alkali-activated binder as stabilizer in compressed earth blocks

J Ongpeng, E Gapuz, J J S Andres, D Prudencio, J Cuadlisan, M Tadina, A Zacarias, D Benauro and A Pabustan

De La Salle University, 2401 Taft Ave, Malate, Manila, 1004 Metro Manila, Philippines.

Email: jason.ongpeng@dlsu.edu.ph

Abstract. Compressed earth blocks (CEB) has number of advantages: cost and energy efficient, eco-friendly, non-toxic, and fireproof. It is composed of available compressed soil near project site with binders as stabilizers. From literature, adding ordinary Portland cement (OPC) as stabilizer is practiced. However, the use of OPC produces high carbon footprint in its production phase. This paper aims to use Alkali-activated (AA) binder as stabilizer for the CEB to promote sustainable construction. It uses a combination of fly ash (FA) mixed with Sodium Hydroxide (NaOH) to produce the stabilizer. Compressive strength and water absorption using AA binder as stabilizer in CEB are investigated. Total of fifty-two CEBs with dimensions of 295mm x140mm x100mm are made as an alternative to conventional concrete hollow blocks with a minimum value of 2.50MPa compressive strength from the provision of Philippine National Standard (PNS). The AA binder ratio of 5% and 15% produced compressive strength of 0.42MPa and 2.92MPa, respectively. Additionally, AA binder ratio of 10% produced lowest percentages of water absorption at 12.83%. It shows that the use of CEB with AA binders is possible in achieving sustainable construction building materials.

1. Introduction

The housing and construction industry is a component affecting national economic growth. World’s population are deprived of housing because of expensive construction materials and shortages on market supply. Earth, as the oldest building material, is used inactively due to the introduction of technological advancements in building materials such as steel, concrete, and bricks. In utilizing earth, Compressed Stabilized Earth Block (CSEB) is introduced. CSEB is a common construction material made originally from moist soil compressed at high pressure to form blocks with additives in order to stabilize the block and prevent damage. Previous research showed CSEB with sugarcane bagasse ash used as stabilizer had beneficial increase in its compressive strength [1]. Another research showed that clay type of soil with 20% rice husk ash yielded highest compressive strength of 5.55 MPa. In addition, with the use of Laterite in CSEB, it yielded maximum compressive strength of 4.9 MPa. Both of which exceeded standards of commercial unfired clay brick [2].

According to state weather bureau, Philippine Atmospheric Geophysical and Astronomical Services Administration (PAGASA), Philippines is visited by at least 20 tropical cyclones every year. As consequence, heavy rains yield flooding and flooding yield to soil saturation. Flooding commonly occurs because of poor management in drainage system. Still, heavy rains saturate the soil resulting to the destabilization of CEBs. Introduction of chemical agents such as cement, fibers, or geopolymers are therefore required in order to stabilize the CEB. When the soil is stabilized with 10% of cement and...
chemical agents, the highest compressive strength of 4.949 MPa and water absorption of 21.54% was achieved [3]. Geopolymers have been shown to exhibit superior mechanical properties to those of Ordinary Portland Cement (OPC). They are the results of the hardening of the alkali activated aluminosilicate constituent of the binding system and the action of the technologic conditions of the hardening [4]. Geopolymer concrete (GPC) is seen as a potential alternative to OPC, and an opportunity to convert a variety of waste streams into useful by-products. Furthermore, geopolymer development desire to reduce greenhouse gas emissions from the production of concrete products [5]. The geopolymerization reaction occurs in the alkaline solutions with aluminosilicate oxides and silicates (either solid or liquid) as reactants. In addition, the mechanism involving the dissolution of the aluminum (Al) and silicon (Si) species from the surface of the source material as well as the surface hydration of undisclosed particles. Afterward, the polymerization of active surface groups and soluble species take place to form a gel, generating subsequently a hardened structure [6].

Durability is also critically affected by wind and water (rainfall). Measuring durability properties of CEB is important because earth blocks may easily erode under water (rainfall) and also the particles wear off under abrasion. The compressed earth blocks that were reinforced with natural fibers improved the blocks resistance to the water spray. The inclusion of fibers in the blocks helped in reducing the erodibility rate of the blocks though, there were some degree of damage. This means the addition of natural fibers does not completely prevent erosion but reduces the impact of erosion in the blocks. The surface of the fiber reinforced blocks eroded rapidly in depth than the internal part. This is because the erosion started on the surface of the blocks, but as the erosion moves internally, a number of fibers encountered clustered together and therefore protect the particles of the soil from being washed away [7].

In this paper, the introduction of Alkali Activated (AA) materials as full replacement to ordinary Portland cement was considered. This is to promote sustainable construction and building materials since production of ordinary Portland cement is damaging to the environment and the supply of materials to remote areas is challenging. Alkali Activated materials or sometimes known as Geopolymers consist of Metakaolin and Sodium Hydroxide. For a 15% geopolymer content, the CEB produced displayed comparable results compared to 8% Original Portland-Cement stabilized CEB in particular with regards with their stability in water [3]. Durability properties of CSEB is crucial since it may erode under water and particles may wear off under abrasion. To improve durability against erosion, fibers are added such that the internal portion of the blocks are clustered together providing protection of the soil from being washed away [8].

2. Materials and Methods

Compressive strength and water absorption are used to determine the mechanical properties of the CSEB in accordance to ASTM C39 [9] and ASTM C1585, respectively. The study was limited to the soil from project site at Camp 1, Rosario, La Union, Philippines. It is situated about 44 kilometers away from Baguio City, the summer capital of the Philippines, 35 kilometers away from Benguet Provincial Capital. The soil analysis for CEB production from the given project location was considered using moisture content (ASTM D2216) [10], specific gravity (ASTM D854) [11], Atterberg’s Limit (ASTM D4318) [12], Granular Analysis (ASTM D6913) [13], and Soil Classification (AASHTO). Seen in Figure 1 is the particle size distribution, and the soil classification in Table 1 as poorly graded gravel, and silty, clayey gravel and sand, respectively.
Table 1. AASHTO soil classification analysis.

| Sample passing #200: | 7.8044 < 35% |
|----------------------|-------------|
| Material:            | Granular    |
| Percentage passing #10 Sieve: | 79.1641   |
| Percentage passing #40 Sieve: | 46.9619    |
| Percentage passing #200 Sieve: | 7.8044     |
| Plasticity Index     | 22.9654019 >11% |
| Liquid Limit         | 41.1140833 > 41% |
| Soil Classification  | A-2-7       |
| Soil Type:           | Silty or Clayey Gravel and Sand |

Figure 1. AASHTO soil classification analysis.

Table 2 shows the number of specimens with the design mix comprising of the raw materials in kilogram such as soil content, fly ash, NaOH, Molarity, and water content. The size of the block is 295mm x140mm x100mm. Table 3 shows the control specimens using OPC with soil, cement, and water content. Compressive strength test was done after curing stage of 7 and 28 day. The abbreviation of the specimens was classified as G for geopolymer or AA binder, while C for OPC binder with the digits representing the content of the binder (i.e. G 10% means AA binder with 10% content).
Table 2. AA materials design mix.

| Specimen ID | Number of specimens | Soil Content (kg) | Fly Ash Content (kg) | NaOH content (kg) | AA Molarity (M) | AA/Water content |
|-------------|---------------------|-------------------|----------------------|-------------------|----------------|------------------|
| G 5%        | 5                   | 5.166             | 0.325                | 0.0649            | 0.542          | 2.963            |
| G 10%       | 5                   | 5.841             | 0.649                | 0.1298            | 1.101          | 2.918            |
| G 15%       | 5                   | 5.517             | 0.974                | 0.1947            | 1.672          | 2.872            |

Table 3. Ordinary Portland cement design mix.

| Specimen ID | Number of specimens | Soil Content (kg) | Cement Content (kg) | Optimum water content (kg) |
|-------------|---------------------|-------------------|---------------------|---------------------------|
| 0%          | 5                   | N/A               | N/A                 | N/A                       |
| C 5%        | 5                   | 6.166             | 0.325               | 0.0974                    |
| C 10%       | 5                   | 5.841             | 0.649               | 0.1947                    |
| C 15%       | 5                   | 5.517             | 0.974               | 0.2921                    |

The samples were covered by plastic to simulate wet curing. The use of the Universal Testing Machine (UTM) in the Materials and Testing Laboratory of Saint Louis University determined the compressive strength capacity of a single CSEB in accordance to ASTM C39. A single CSEB was submerged to the water to determine its absorption rate in accordance to ASTM C1585 and to further study the behavior of CSEB when in contact with water.

3. Results and Discussions
The objective of the study is to provide an alternative material for concrete hollow blocks especially in remote mountainous areas were transportation is challenging. Concrete hollow blocks (CHB) in the Philippines are the most commonly used masonry blocks. This construction building material can be classified as non-load bearing or load bearing blocks. The ingredients use for the production of CHB are: ordinary Portland cement with water and aggregates. On the other hand, this study using CEBs focused on the compressive strength that was designed to conform to the standard based from the Philippine National Standards (PNS) having a baseline value from sample size of 5 units of non-load bearing CHBs (type 2) of 2.5 MPa compressive strength. Shown in Figure 2 are the individual results of the compressive test at an age cured for 28 days. While shown in Figure 3 is the average compressive strength of the CEBs. The CEBs with OPC of 5%, 10%, 15% reached the baseline value with a compressive strength of 2.5 MPa, 3.8 MPa, and 4.4 MPa respectively, while CEBs with geopolymer, only the blocks with 10% and 15% geopolymer content passed with a compressive strength of 2.5 MPa and 2.8 MPa, respectively.
The amount of geopolymer and OPC in the mixture had an effect on the shape and size of cracks that was formed during the compressive strength test. The typical failure of the CEBs is shown in Figure 4. This finding supports the results of the previous study conducted [14].
For the water absorption test, the CEBs (dry) are immersed completely in water for 24 hours. The dry weight and wet weight of each sample is recorded. Use the formula \(((M2 - M1)/M1)*100\) to get the water absorption (%) by mass of each blocks. The results of water absorption test are presented in Table 4. According to Indian Standard IS 3495 (Part 2) [15], the water absorbed by the block should not exceed 15%. It can be observed that CEBs with 10% OPC, 15% OPC, 10% geopolymer, 15% geopolymer conformed to the aforementioned standard with water absorption of 12.96%, 10.39%, 12.83, and 11.83%, respectively.

| Specimen ID | Dry Weight, M1 (kg) | Wet Weight, M2 (kg) | Water Absorbed (%) |
|-------------|---------------------|---------------------|---------------------|
| C5%         | 6.44                | 7.48                | 16.15               |
| C10%        | 6.48                | 7.32                | 12.96               |
| C15%        | 6.74                | 7.44                | 10.39               |
| G5%         | 5.90                | 5.47                | N/A                 |
| G10%        | 6.74                | 7.61                | 12.83               |
| G15%        | 6.55                | 7.33                | 11.83               |

4. Conclusions and Recommendations

Construction project sites in rural and mountainous regions experiences logistical problems which in turn results to increase in cost and unsustainable development. This study focused on replacing commonly used masonry bricks which is concrete hollow blocks with compressed earth blocks (CEB). The use of available soil near the project location were used to arrive at an acceptable CEB in compliance with the compressive strength and water absorption. Comparison of CEBs using ordinary Portland cement and Alkali activated materials as binders/stabilizers were investigated. As per the requirement of the Philippine National Standards, the average compressive strength is 2.5 MPa and the absorption test, using the Indian Standard 3495 (Part 2), the sample should not absorb more than 15% of water. Based from the results, the design mix of CEB with ordinary Portland cement and Alkali activator (AA) of 10% and 15% conformed to the compressive strength and water absorption requirements. The use of
alternative construction materials and its ingredients like CEB and AA are examples of sustainable construction materials to reduce carbon footprint in the construction industry.

References

[1] Salim RW, Ndambuki JM and Adedokun DA. Improving the Bearing Strength of Sandy Loam Soil Compressed Earth Block Bricks Using Sugarcane Bagasse Ash. *Sustainability*, MDPI, 6(6), 1-11, June 2014.

[2] Riza FV, Rahman IA and Zaidi AMA. A brief review of Compressed Stabilized Earth Brick (CSEB). *2010 International Conference on Science and Social Research (CSSR 2010)*, IEEE 2010.

[3] Nagaraja, A., Amal, K.K., Bhavin Bhaskaran, P.P., Dilmohan, K., & Mohind Mohan, K. P. (2018). Study on Compressed Stabilized Earth Blocks by Using Chemicals, IOSR Journal of Applied Geology and Geophysics(IOSR-JAGG). Retrieved November 13, 2018, from http://iosrjournals.org/iosr-jag/papers/Vol.%206%20Issue%203/Version-3/H0603035156.pdf

[4] Krizma, M., Palou M., & Zivica, V. (2014). Geopolymer Cements and their properties: A Review. Retrieved on December 19, 2018 from https://www.researchgate.net/publication/276846508_Geopolymer_Cements_and_Their_Properties_A_Review

[5] Mustafa AL Bakri, A. M., Kamarudin, H., Binhussain, M., Khairul Nizar, I., Rafiza, A. R., & Zarina, Y. (2013). Comparison of Geopolymer Fly Ash and Ordinary Portland Cement to the Strength of Concrete. Retrieved on December 19, 2018 from https://www.researchgate.net/publication/272138090_Comparison_of_Geopolymer_Fly_Ash_a nd_Ordinary_Portland_Cement_to_the_Strength_of_Concrete

[6] Alvarez-Ayuso, E., Querol, X., Plana, F., Alastuey, A., Moreno, N., & Izquierdo, M. et al. (2008). Environmental, physical and structural characterisation of geopolymer matrixes synthesised from coal co-combustion fly ashes. *Journal of Hazardous Materials*, 154(1), 175-183.

[7] Gowda RPC and Zapata CE. Effect of Bagasse Fiber on the Properties of Compressed Cement Stabilized Earth Blocks. *Geotechnical and Structural Engineering Congress 2016*, ASCE.

[8] Sore SO, Messan A, Prud'homme E, Escadeillas G, Tsobnang F. Stabilization of compressed earth blocks (CEBs) by geopolymer binder based on local materials from Burkina Faso. *Construction and Building Materials*, 165, 2018, 333-345.

[9] ASTM C39: Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.

[10] ASTM D2216-19: Standard Test Method for Laboratory Determination of Water Content of Soil and Rock Mass.

[11] ASTM D 854-14: Standard Test Method for Specific Gravity of Soil Solids by Water Pycnometer.

[12] ASTM D4318-17E1: Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils.

[13] ASTM D6913: Standard Test Method for Particle-Size Distribution of Soils Using Sieve Analysis.

[14] Ongpeng JM, Gapuz E, and Roxas CL. Optimization of mix proportions of compressed earth blocks with rice straw using artificial neural network. *2017IEEE 9th International Conference on Humanoid, Nanotechnology, Information Technology, Communication and Control, Environment and Management (HNICEM)*, IEEE 2017.

[15] IS 3495 Part 2: Indian Standard Test Method for Determination of Water Absorption