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Original Research Article

Biomass Geopolymer Composite Adobe Blocks as an Improved Construction Material

***Salahudeen, A.B. and Bakare, E.T.**

Department of Civil Engineering, University of Jos, Jos, Nigeria.
*muazbj@gmail.com

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ABSTRACT

This study focused on investigating alternative construction materials for low-cost housing due to the skyrocketing costs of conventional building materials. The study methodology includes laboratory evaluation of the characteristics of 150mm×100mm×100mm unburnt earth blocks improved with corncob ash (CCA) geopolymer cement. Blocks produced at various percentages of 0, 10, 20, 30, 40, and 50% mix of clay/CCA geopolymer were crushed at 7 and 28 days of curing to observe their compressive strength. The block samples were observed to absorb a higher amount of water with an increase in the percentage content of CCA Alkali-Silica geopolymer. Careful observations were made on several properties of the samples such as the presence of cracks/voids and the level of shrinkage after 28 days of curing. Based on the compressive strength result of 5.87 N/mm^2 obtained at 28 days, it was recommended that up to 50% CCA geopolymer content be used to replace cement by weight.

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1. INTRODUCTION

As a material used in the creation of most of the structures in the world like buildings, bridges, roads, dams and other important infrastructural facilities, cement is known to release excess amount of carbon dioxide. There is currently a global emission of over 4 billion tonnes of carbon dioxide annually (Tavakoli *et al.,* 2021; Salahudeen *et al.,* 2023). However, environmental preservation, civilization and sustainable infrastructural development are globally recognized as convincing steps for future preservation. This important approach needs a careful balance in factors affecting the economic, environment and society. Hence, it must be environmentally friendly, affordable and beneficial to human well-being. Moreover, the rapid increase in the price of building materials is a big problem, particularly for low-income earners in developing countries like Nigeria who find it difficult to acquire convectional building materials. Therefore, it is indispensable to seek alternative options to Portland limestone cement (PLC) utilization in the infrastructural development. Most of these alternative and sustainable construction binders are agro-industrial wastes (Antico *et al.,* 2017; Sharbatdar *et al.,* 2020; Onyelowe *et al.,* 2021; Salahudeen, 2023).

Mud and clay are among the first building materials used by humans because of their ease of workability and their adhesive properties when reinforced with natural fibers. To enhance structural durability, agricultural wastes like straw, grass, rice husks and other fibers have been used as reinforcing materials and to provide strength and withstand harsh weather conditions (Akinyele *et al.,* 2015; Shailza and Leon, 2017;). In recent time, research into the use of agro-industrial waste materials as a partial replacement for cement has led to the discovery of potential cementitious materials of ashes from biomass. Some of these materials include rice husk, corncob ash, saw dust, groundnut shell, etc. (Salahudeen *et al.,* 2014; Antico, 2018; Salahudeen and Sadeeq, 2019; Onyelowe *et al.* 2020;). The outcome of these researches indicated that the ash of these agro-industrial waste materials have high silica content that qualifies them for use as pozzolanic materials. Further, the use of these agricultural waste materials constitutes an environmental-friendly approach of large quantity waste disposal which would otherwise pollute land, water and air (Onyelowe *et al.,* 2019; Sadeeq *et al.,* 2016; Salahudeen and Sadeeq, 2018).

The Raw Materials Research and Development Council of Nigeria conducted a study on local cementitious materials, they observed that there are several of these materials readily available and capable of been used as substitute for cement. Corncobs, an agricultural process residue, is one of the potential alternative binding materials for cement which is the pozzolana used for this study. The yield of corncobs may range from 1.42 to 1.53 dry ton/ha (Cooper and Laing, 2007; Hanway, 1963). After maize harvest, the residues include cobs, husk, leaves and stalks. Around 15-20% of the corn residues is corn cobs (Salahudeen *et al.,* 2019; Onyelowe *et al.,* 2019; Pordesimo *et al.,* 2004). The aim of the study was to investigate the possibility of using corncob ash geopolymer cement as an alternative and sustainable binding material to ordinary Portland cement.

2. MATERIALS AND METHODS

2.1. Materials

The materials used for the study, prepared samples and location maps of obtainment are shown in Figures 1 - 4. The chemical composition of the corncob ash used is presented in Table 1. The corncob ash used in this study is the ash obtained from the process of burning corncobs. The corncobs used for this experimental work were obtained locally from a local farm situated at Zarmaganda Jos South LGA of Plateau State, Nigeria which lies within (latitude 9.835953^0 N and longitude 8.869755^0 E). The ash passing through B.S. sieve no. 200 (0.075 mm) were used in accordance with BS 1924 (1990) for the replacement of cement. The earth (clay-soil) used in this study is an ordinary clay soil obtained from a remote village situated along La'mingo dam road, Jos Plateau State (Latitude 9.888890 N and longitude 8.912347 E). The soil was collected at a depth of 0.5 m to avoid organic/biodegradable contents in the material to avoid inaccuracy of results. Sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were used as alkaline activators which was mixed with concorb ash to form the geopolymer cement (GPC) which is a product of reaction between alumina-silicate and alkaline solution. The alkaline activators were mixed in the ratio of 0.7:0.3 i.e., ratio of NaOH to Na_2SiO_3, while the ratio of geopolymer to corncobs ash (CCA) was 1:1. CCA passing sieve No. 200 with aperture of 0.075 mm was used in preparing the geopolymer cement.

Figure 1: (a) Corncobs during incineration (b) Corncobs ash after incineration.

Figure 2: (a) Casted earth block samples (b) Earth block samples during crushing

Table 1: Chemical composition of corncob ash (Salahudeen and Sadeeq 2018)

Chemical compound	SiO_2	CaO	Al_2O_3	MgO	Fe_2O_3	Na_2O	P_2O_5	SO_3	K_2O	Loss on ignition
Amount (%)	52.77	5.89	6.40	3.10	3.78	0.70	3.32	2.05	10.62	10.45

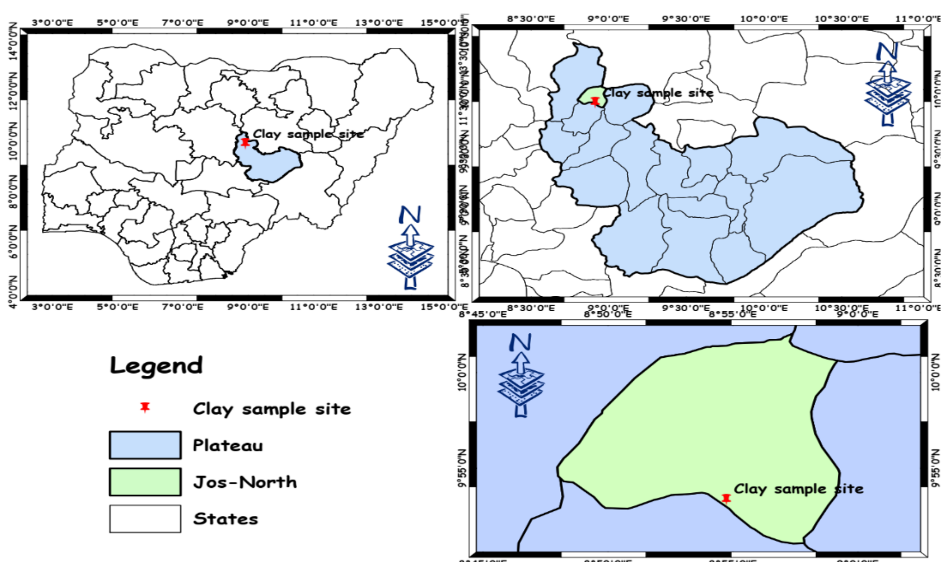

Figure 3: Location map of clay soil

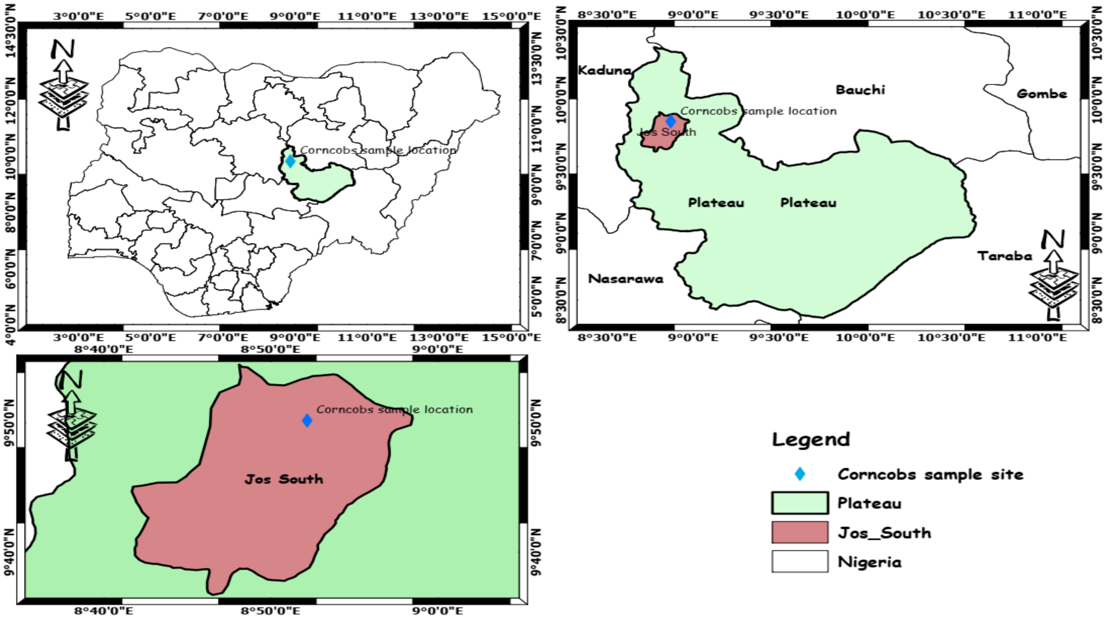

Figure 4: Location map of corncobs

2.2. Experimental Procedures

This experimental work presents the effects of using Corncobs Ash Geopolymer (CCA - GP) as a substitute for cement in blocks production. This experimental work is based on the comparative study of earth (clay) mix made with cement (PLC) and by partial replacement of the cement (PLC) with Corncobs ash Geopolymer (CCA - GP). Furthermore, six (6) different replacement levels of CCA-GP replacing cement at 0, 10, 20, 30, 40 and 50% were considered with the 0% being the control sample. The geopolymer mix mortar was filled into 150 mm x 100 mm x 100 mm greased metal mould then vibrated on a vibrating table to produce the blocks.

The laboratory tests on soil were conducted to determine the particle size distribution and consistency limits of the soil in accordance with British Standard 1377 (1990) for the natural soil and British Standard 1924 (1990) for the modified soil samples. Tests conducted on the casted block samples include water absorption test, ultrasonic pulse velocity (UPV) test, the volumetric shrinkage and the compressive strength test. Water absorption test was conducted to determine the quantity of water a block absorbs in a given period of time by total immersion (submerging) of the blocks in water and taking weight measurements at every 3 minutes intervals up to a maximum time of 30 minutes. The ultrasonic pulse velocity (UPV) tests were carried out with the Ultrasonic Pulse Analyzer equipment which shows the time in microseconds from when a wave reaches the receiving transducer measured from the time it leaves the transmitting transducer. The UPV was done by direct, semi-direct and indirect methods. The volumetric shrinkage assessment was performed to simulate the field condition during summer period when the blocks are expected to significantly loss moisture. It was performed using a digital Vernier calliper accurate to 0.01mm to measure dimensions (L x B x H) used to compute the volumetric shrinkage strain. As a simulation of field condition, the block specimens were air dried on a laboratory bench for a period of 30 days at a uniform temperature of 28 ± 2^{o}C. The compressive strength test was conducted using the destructive and non-destructive methods separately after 7 and 28 days of curing. The destructive compressive strength test was carried out using the universal testing machine while the non-destructive compressive strength test was performed using the Rebound hammer.

3. RESULTS AND DISCUSSION

3.1. Soil Classification and Initial Properties

The engineering properties of the natural soil classified it as an A-6 and low plasticity clay CL based on AASHTO and USCS classification systems respectively. The unmodified soil has consistency limits values of 27.39% (liquid limit), 16.73% (plastic limit) and 10.66% (plasticity index) with 39.35% of its finest particles smaller than the BS sieve #200.

3.2. Sieve Analysis

As the soil is basically silty clay type of soil, sieve analysis test was performed to determine the particle size distributions of the soil sample. The results of the sieve analysis test for different replacement levels of cement with corncobs ash geopolymer (CCA-GP) is presented in Figure 5. The addition of CCA-GP caused solidification of the particles resulting in a progressive increase in the amount of coarse content and decrease in the fine content. This observed trend is consistent with the observations in similar researches by Sadeeq *et al.* (2015) and Salahudeen *et al.* (2014).

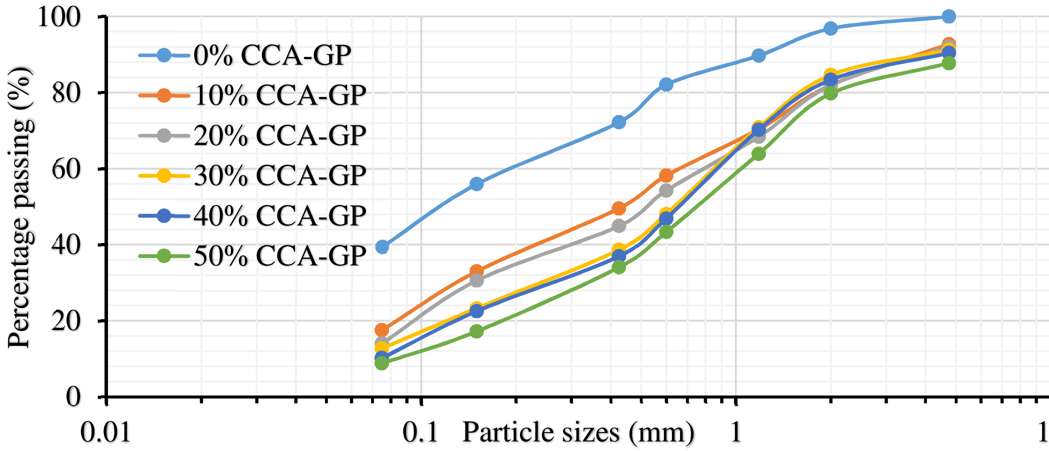

Figure 5: Particle size distribution curves for different percentages of soil-CCAGP mix

3.3. Consistency Limits

The Atterberg limits define the boundaries at which the plastic soils transition between solid, semi-solid, plastic, and liquid states based on moisture contents at the points where the physical changes occur. The results of Atterberg limits are presented in Figure 5. The liquid limit and plastic limit of the CCA-GP modified soil at different percentage replacement (0% - 50%) increased consistently up to highest mix content of 50% while the plasticity index decreased. It was observed by Suhail *et al.* (2008) and Salahudeen *et al.* (2019) that the depressed double layer thickness of the soil is responsible for the decrease in plasticity of soil when mixed with a stabilizing agent which results from bonding capability of the pozzolanic material and the cation exchange reaction by the detected cations as presented on Table 1.

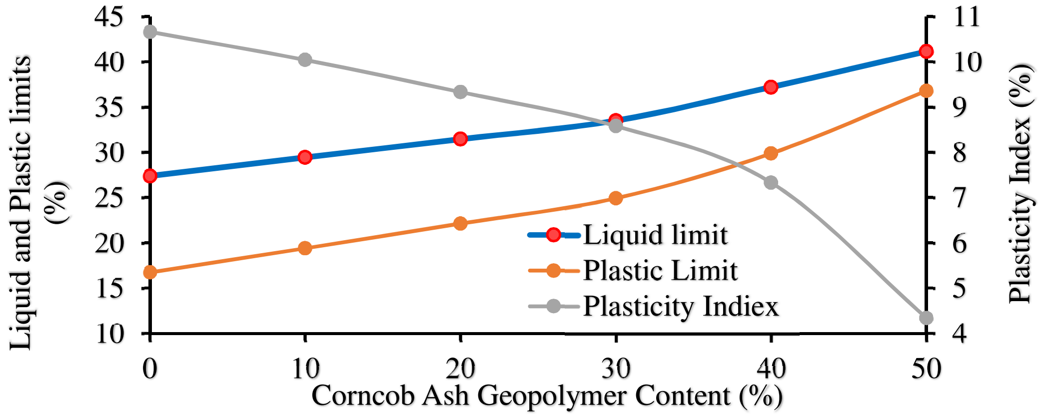

Figure 6: Consistency limits results with corncob geopolymer content

3.4. Water Absorption Experimentation

The water absorption test was conducted to determine the quantity of water a block absorbs in a given period of time. The test was carried out to simulate the practical situation where the blocks may be used in external walls that could be subjected to rain or flood water absorption. The results of water absorption by weight measurement every 3 minutes up to maximum period of 30 minutes is presented in Figure 7 while that of percentage gain in weight is presented in Figure 8. It was observed that the block samples mostly get saturated after about 25 minutes of soaking in water. It was also observed that the water absorption capability of the blocks increases with increase in the CCA-GP content. This may be due to the fact that CAA is an organic material with a high loss on ignition value (10.45%). The increase in water absorption with increase in CCA-GP content might be due to increased voids in the treated block samples compared with the untreated ones (De Silva and Perer, 2018; Kazmi *et al.,* 2016).

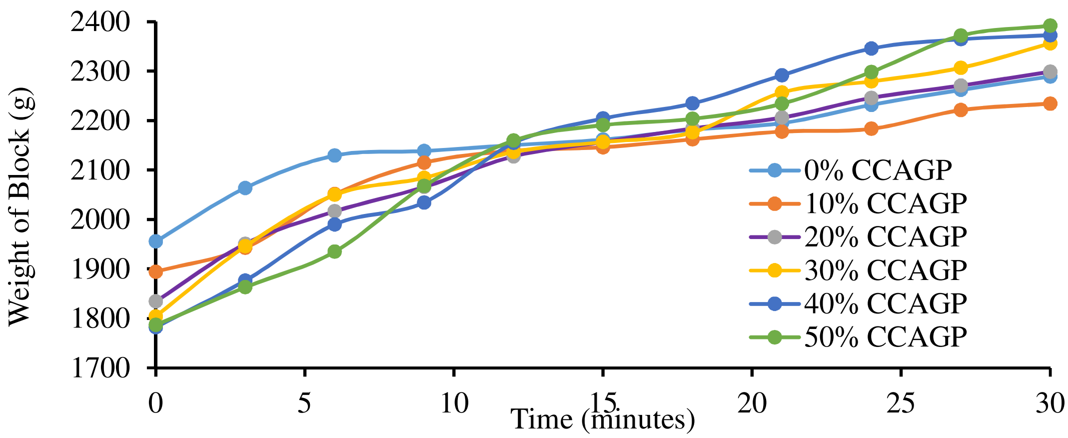

Figure 7: Results water absorption by weight for different percentages of soil-CCAGP mix

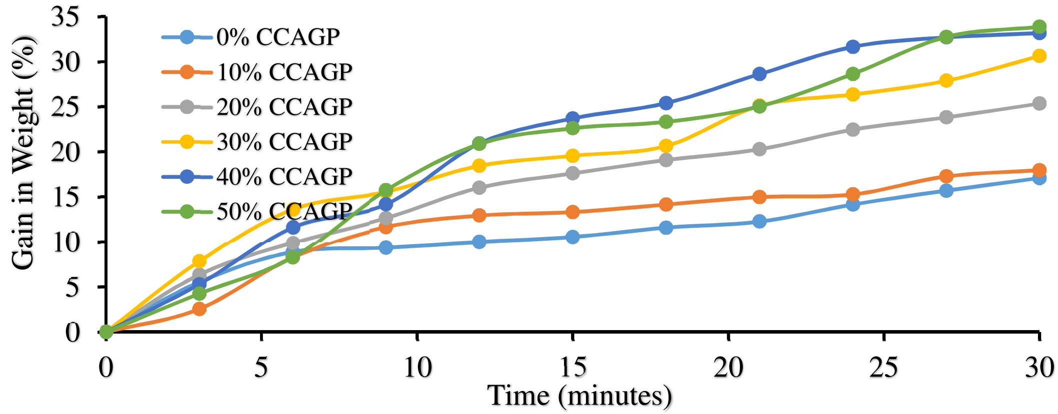

Figure 8: Results water absorption by percentage gain in weight for different percentages of soil-CCAGP mix

3.5. Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) test is used to determine the presence of voids or cracks or any form of openings in the inner structure of the blocks. It is a method of determining the tortuosity in the blocks. It is noteworthy that while porosity measures the presence and amount of voids in a medium, tortuosity measures the interconnectivity of those voids. The results of the UPV tests (Direct, Semi-Direct and Indirect) are presented in Figure 9. It was observed that all the three phases of the UPV indicated decrease in pulse velocity which is an indication of presence of pores/voids or cracks within the blocks. The presence of voids will create vacuum that will decrease the rate of passage of the pulse waves thereby decreasing the pulse velocity. It is obvious from Figure 9 that the amount and interconnectivity of the voids increases pregressively with increase in CCA-GP content.

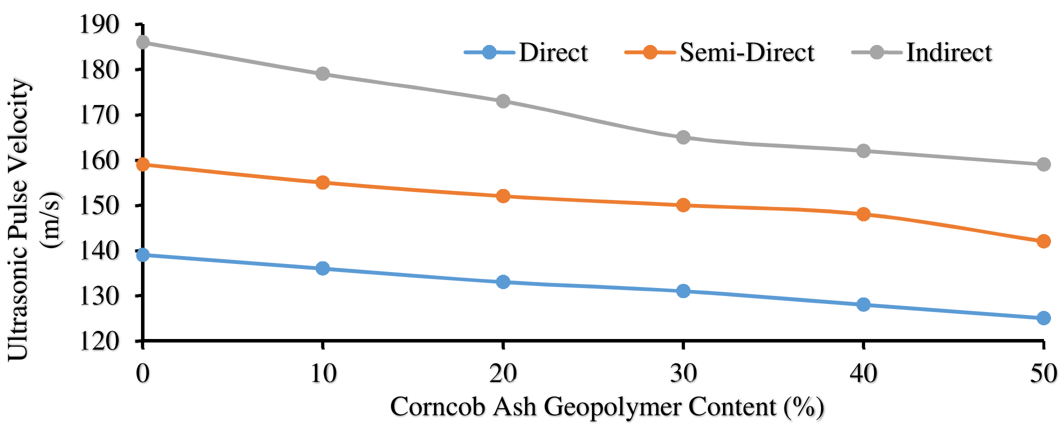

Figure 9: Ultrasonic pulse velocity results with corncob geopolymer content

3.6. Volumetric Shrinkage Analysis

The volumetric shrinkage strain results are presented in Figure 10. This experiment was performed to simulate the actual field condition when the blocks will experience drying and shrink volumetrically after losing moisture. It was observed that although the volumetric shrinkage strain amount was not pronounced, it increased progressively with increase in the CCA-GP content.

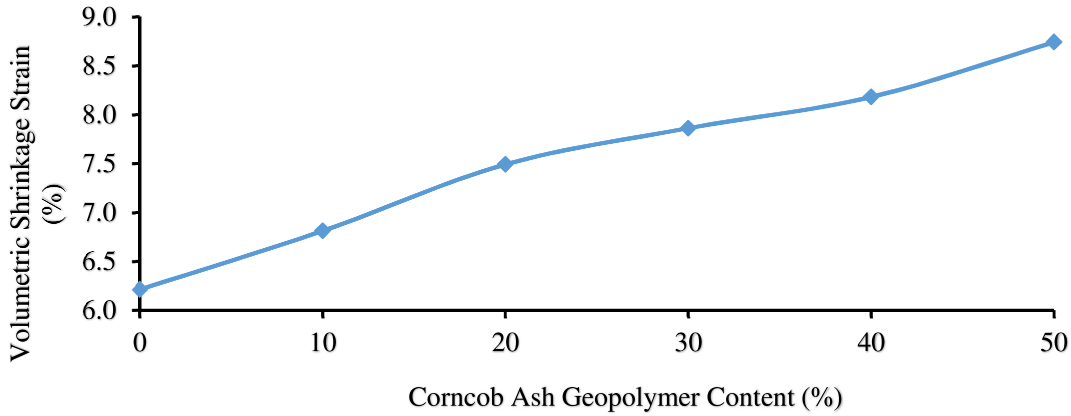

Figure 10: Volumetric shrinkage results with corncob geopolymer content

3.7. Compressive Strength Test

The compressive strength test was conducted by both destructive and non-destructive methods at 7 and 28 days curing periods. The results of the compressive strength tests are presented in Figures 11 and 12 for the 7 and 28 days curing periods respectively. It was observed that the compressive strength generally decreased with increase in CCA-GP content. This observed trend is consistent with previous study by Agbede and Joel (2011). In most standards, the destructive test values are used for recommendations. For the destructive method used for this study, peak strength values of 4.62 and 5.87 N/mm^2 for the untreated block samples were observed at 7 and 28 days respectively. A minimum compressive strength value of 2.8 N/mm^2 was recommended by the British Standard (1985) fired bricks. A value of 2 - 4 N/mm^2 was recommended for smaller structural loads by several building authorities around the world (Deboucha and Hashim, 2011). For this study, all the strength test results up to the maximum CCA-GP content of 50% (3.24 N/mm^2) met the minimum recommended value of 2.8 N/mm^2 at 28 days curing period. Strength resulting from chemical reactions of this nature are mostly associated with formation of hydrates of calcium aluminate and calcium silicate that caused bonding of the finer particles of the soil material. It is understood that the Ca^{2+} in the geopolymer reacted with the metallic ions of lower valence in the soil structure at the time of exchange of ions which yielded agglomeration of the fine contents of the soil (Sadeeq and Salahudeen, 2018).

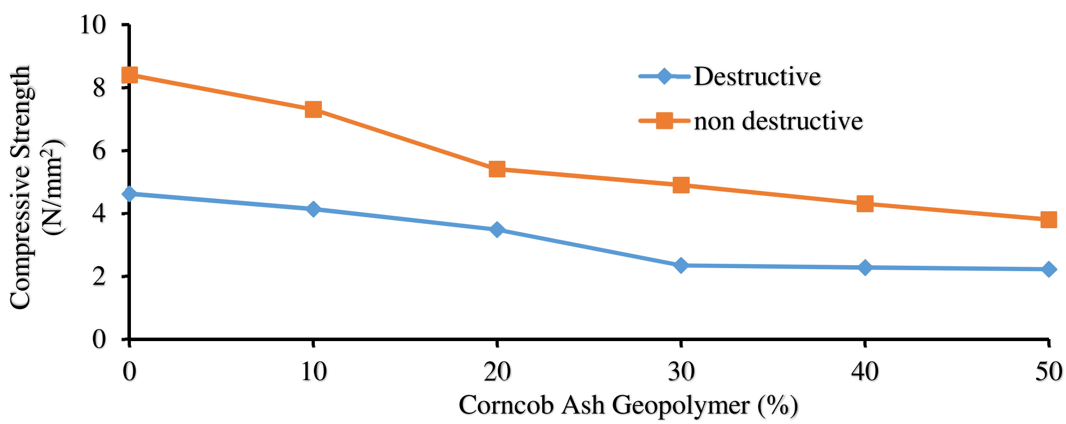

Figure 11: Compressive strength test results with corncob geopolymer content (7 days)

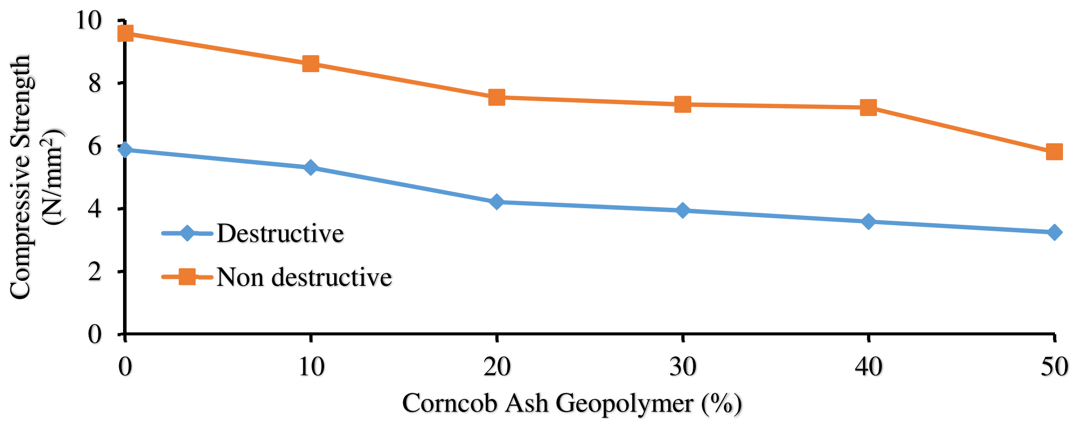

Figure 12: Compressive strength test results with corncob geopolymer content (28 days)

4. CONCLUSION

This study was carried out to determine the effectiveness of replacing ordinary Portland cement with corncob ash geopolymer (CCA-GP) in the production of compressed earth blocks for low-cost housing purpose. CCA-GP is eco-friendly and less energy-intensive binding material that can be utilized in the production of affordable building blocks. The blocks used for this study are of dimensions 150mm×100mm×100 mm. Blocks were produced at various percentages of 0, 10, 20, 30, 40, and 50% mix of clay/CCA geopolymer. The results show significant improvements in the characteristics of the modified blocks. The addition of CCA-GP caused solidification of the fine particles resulting in a progressive increase in the amount of coarse content and decrease in the fine content. It was also observed that the water absorption capability of the blocks increases with increase in the CCA-GP content. The ultrasonic pulse velocity indicated a decrease in pulse velocity which is a confirmation of presence of voids and/or cracks within the blocks. Although the compressive strength decreased with addition of CCA-GP, the minimum value obtained from the destructive method after 28 days curing was 3.24 N/mm^2 at 50% CCA-GP content. This minimum observed value satisfied the minimum compressive strength value of 2.8 N/mm^2 recommended by the British Standard for precast concrete masonry units and load bearing fired clay blocks.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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