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Effect of guinea-corn husk and saw-dust ash on the mechanical and microstructural properties of interlocking concrete block

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Abstract

Interlocking concrete blocks have gained significant attention in sustainable construction due to their inherent advantages, including reduced mortar requirements and ease of assembly. This study investigates the influence of incorporating Guinea-Corn Husk Ash (GCHA) and saw-dust ash (SDA), on the mechanical and microstructural properties of interlocking concrete blocks. Concrete mix proportions were established with a mix ratio of 1:2:4 (cement-GCH and SDA), and a water-to-cement (w/c) ratio of 0.6. The aggregates, GCHA, SDA, and granite, underwent sieve analysis to determine particle size distribution in accordance with BS 812-103.1standards. Manual concrete mixing was carried out following the procedures outlined, and the resulting concrete mixes were poured into plastic molds and subsequently placed in a curing room at a temperature of 27 ± 5 oC. The concrete samples treated with cement and subjected to Scanning Electron Microscope (SEM) analysis at different magnification rates (x8000, x9000) and resolutions (10 µm, 50 µm, 100 µm) for a curing period of 56 days, were then analyzed. For the elemental composition of the cement samples, the control sample indicates that calcium is the major element in ordinary Portland cement, constituting 69.10 wt%. However, for samples with blended cement of guinea-corn stalk and sawdust ash, calcium remains the major element but with varying percentages of 60.30, 40.00, 50.00, 56.15, 50.00 wt%, respectively. The results suggest that the addition of GCHA and SDA with cement leads to a decrease in calcium composition, potentially impacting construction.

Keywords: Sustainable Construction; Blended Cement; Guinea-Corn Husk; Saw-Dust Ash; Interlock Concrete

1. Introduction

In recent years, there has been a growing emphasis on blended cements due to their environmental sustainability and cost-effectiveness stemming from reduced clinker and energy inputs. Blended cements, formed by combining Portland cement clinker with materials such as pozzolana and granulated blast furnace slag, have garnered significant attention. Prior research has delved into various facets of concrete technology, exploring the utilization of quarry rock dust (QRD) and steel fibers (SF) in geopolymer concrete, the development of structural lightweight aggregate concrete (SLWAC) using sintered fly ash aggregates (SFA), and the examination of autoclaved aerated concrete (AAC) blocks manufactured from industrial waste materials.

For instance, the impact of incorporating QRD and SF on the properties of fly ash (FA) and ground granulated blast furnace slag (SG)-based geopolymer concrete (GPC) subjected to elevated temperatures has been studied [1]. The researchers explored 18 different mix proportions, varying QRD content (0-20%) and steel fiber inclusion (0.75% and 1.5%). Results showed that mechanical strength increased in GPC mixes without steel fibers with up to 15% QRD content at 28 days, but further increases led to a decline. Addition of steel fibers enhanced compressive, tensile, and

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flexural strength, with optimal performance observed at 15% QRD and 0.75% steel fibers. Another study [2] focused on developing SLWAC using SFA with different binders, including Portland Pozzolana Cement (PPC), Ordinary Portland Cement (OPC), and Micro Fibre Cement (MFC). Mechanical behaviors such as compressive strength, split tensile strength, flexural strength, and impact resistance were investigated at various water-cement ratios, alongside microstructure analysis. Findings revealed that SLWAC made from OPC exhibited superior mechanical strength compared to PPC and MFC, attributed to faster hydration and early strength gain.

Additionally, the performance of autoclaved aerated concrete (AAC) blocks fabricated from industrial waste materials, namely fly ash (FA) and ground granulated blast furnace slag (GGBS) was evaluated in [3]. The study investigated the impact of different dosages of GGBS as a partial replacement for cement on the microstructural and mechanical properties of AAC blocks. Employing various analyses including scanning electron microscopy (SEM), X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDAX), and Fourier transform infrared spectroscopy (FTIR), the findings revealed a significant increase in the compressive strength of AAC blocks with the incorporation of GGBS. Moreover, the sustainable development of the construction industry by exploring hybrid alkali-activated cements containing industrial waste or by-products was addressed in [4]. The researchers investigated their radiological behavior using a novel gamma spectrometric method focusing on solid 5 cm cubic specimens. This departure from conventional powder samples provided insights into the eco-efficiency of these cements. Futhermore, the utilization of waste granite dust in manufacturing Interlocking Concrete Block Pavers (ICBP) was investegated in [5]. The study aimed to determine the optimum percentage of waste granite dust as a replacement for sand in ICBP production. Results indicated that 25% waste granite dust enhanced strength, eco-friendliness, and cost-effectiveness, leading to a 5.5% cost saving per cubic meter of ICBP production.

The incorporation of supplementary cementitious materials (SCMs) such as Guinea-corn husk ash (GCHA), fly ash, corn cob ash, and wood ash presents an opportunity to improve concrete properties while addressing concerns about material cost and sustainability. GCHA, derived from the incineration of guinea-corn, a significant agricultural by-product, offers promising potential as a reinforcement material due to its abundance, lightweight nature, renewability, biodegradability, cost-effectiveness, and low abrasiveness [7]. Several studies [8-12] have demonstrated that replacing cement with GCHA enhances the compressive strength of concrete and mortar.

Building on these studies, this work investigates the addition of saw dust ash (SDA) to the well used GCHA to understand if it holds the potentials to ehance the mechanical properties of interlock concrete blocks. We considered this material becuase it has been found to contain 5–10% cellulose, lignin, and hemicelluloses and about 51 to 72% of calcuim, which are necessary for mechanical fitness in structures [13]. Methodologies employed include comprehensive mix design variations, mechanical testing, microstructural analysis, and performance evaluation under different conditions. In particular, we explore the behavior of concrete produced by blending cement with GCHA and SDA at varying percentages to assess the physicochemical and mechanical properties of the blended cement through scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). We then determined the impact of GCHA and SDA on the characteristics of blended cement concrete on hardened properties. The subsequent sections provide a characterization of GCHA and SDA, evaluation of flexural strength, tensile strength, and compressive strength of the mixture, and examination of the structural morphology of the mixed concrete using SEM and EDS.

2. Materials and methods

2.1. Materials

Ordinary Portland Cement (OPC), crushed granite, GCHA and SDA and water were the materials used in this study. OPC was purchased from retail shop within Ogbomoso, Nigeria to serve as the binder, while crushed granite was sourced from a Quarry site and was used as as the main coarse aggregate. GCHA and SDA were sourced locally, and a mixed composite was made by clacining the stalks in the furnace at the temperature of 600 ^{o}C for 4 hours. At this temperature, ashes with amorphous structures and low carbon content were observed. The GCHA and SDA were subsequently sieved using 75 µm (sieve No 200) sieve. The ashes are shown in Figure 1.

Figure 1 Utilzed materials. (A) calcinated GCHA (B) calcinated SDA

2.2. Method

Concrete Mix Proportions of 1:2:4 was consider while the sample (cement, GCHA and SDA, granite) was prepared with w/c ratio 0.6. Thereafter, sieve analysis was conducted on the aggregate (GCHA, SDA and granite) to determine particle size distribution as specified in [14] and concrete mixing was done manually. The concrete mixes was then poured into plastic moulds and placed in the curing room at 27 ± 5 ^{o}C for 24 hours. The concrete specimens were unmoulded and later cured in water at 7, 14, 21 and 28 days. The sample prepared without GCHA and SDA served as the control as shown in Table 1.

Table 1 Batching of the materials for concrete specimens

Specimen	Cement (kg)	GCHA(kg)	SDA(kg)	Granite(kg)
Control (OPC)	1.2	0	0	2.3
95% OPC + 5% GCHA and SDA	1.14	0.03	0.03	2.3
90% OPC + 10% GCHA and SDA	1.04	0.06	0.06	2.3
85% OPC + 15% GCHA and SDA	1.02	0.09	0.09	2.3
80% OPC + 20% GCHA and SDA	0.96	0.12	0.12	2.3
75% OPC + 25% GCHA and SDA	0.9	0.15	0.15	2.3

2.2.1. Testing of Materials and Concrete Samples

Scanning Electron Microscopy was used to determine the micrograph of GCHA. The physical properties of cement and GCHA and SDA to include specific gravity, fineness (specific surface area) and loss on ignition (LOI) were examined while the chemical compositions of cement and GCHA and SDA were determined.

In addition, the workability of fresh concrete were determined by conducting slump and compacting factor, while the density of hardened concrete was evaluated after 28 days of curing in accordance to [15]. Also, splitting tensile strength and compressive strength was evaluated for the 7, 14, 21, and 28 days by employing a 734mm × 458mm × 100mm rectangular shape. Meanwhile, flexural strength of concrete was carried out on a simple prison of 100mm × 100mm × 500mm in size after 28 days of curing in compliance with [14].

2.2.2. Batching

The equipment and tools used are weighing balance, head pan, shovel, hand trowel, concrete cube mould and tamping rod. The GCHA cement concrete consists of the mixture of the GCHA, OPC, sand, granite and water as the raw materials. Batching of the materials was carried out by weight in kilogram. The mixing involved the replacement of 5%, 10%, 15% and 20% by weight of OPC with GCHA during the mixing process. The OPC and GCHA was mixed first before pouring in fine aggregates. Concrete without GCHA served as control for other samples. The batching of the materials required for concrete specimens to produce corn cob ash cement concrete as been presented in Table 1.

2.2.3. Physical Properties Testing

First, we considered the water absorption test. Two blocks were randomly chosen from each group of the specified age for the water absorption testing and was weighed on a scale. After being fully submerged in water for 24 hours, these blocks were then recovered and weighed once more. The percentages of water absorbed by the blocks was estimated as follows:

$$= \frac{W_s - W_d}{W_d} \times 100 \quad (1)$$

Where:

Wa = percentage moisture absorption

Ws = weight of soaked block

Wd = weight of dry block

Both the tensile and compressive strenghts was also examined. The compressive strength was carried out using a compression machine of 2000 kN after the curing days. The concretes, which have been made into cubic shapes, were correctly positioned in the compression testing apparatus and the machine's gear was rotated clockwise after being turned on. When the machine's dial gauge reached failure, the maximum load was considered as the compressive strength. The concrete cubes' compressive strength was calculated using the equation 2 below.

$$Compressive\ Strength = \frac{F}{A}\left(N/mm^2\right) \quad (2)$$

Where:

F = Failure Load

A = Cross Sectional Area of Cube

The tensile spliting test and the spliting force was calculated using Equation 3.

$$f_{ct} = \frac{2F}{\pi Ld}\left(N/mm^2\right) \quad (3)$$

Where:

Where: fct = split tensile strength, in Newton per square millimetre (N/mm^2);

F = maximum load, in Newton (N);

L = distance of the line of contact of the specimen, in millimetres;

d = designated cross-sectional dimension, in millimetres.

3. Results and discussion

3.1. Sieve Analysis

Result of particle sizes analysis of the stone dust for coefficients of uniformity (Cu) and coefficient of (ec) are 4.11 and 1.09 respectively, as shown in Figure 2. It therefore implies that the aggregate sample (i.e. stone dust) is uniformly graded since the coefficient of uniformity is more than 3 [16].

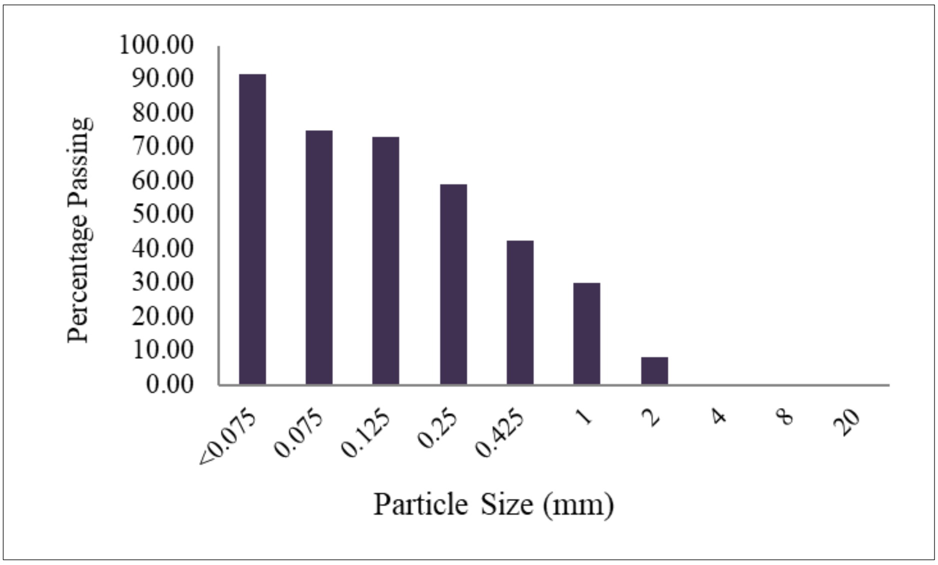

Figure 2 Sieve analysis of fine aggregate

3.2. Compressive Strength Test of Interlocking Concrete Block

Figure 3A shows the results obtained from the compressive strength test for the control samples cured between 7 to 28 days, which ranged from 400N/mm^2 to 433N/mm^2. Meanwhile, samples with 5% blended GCHA and SDA have compressive strenght ranged from 307N/mm^2 to 425N/mm^2 as shown in Figure 3B. Similarly, a range of 205N/mm^2 to 248N/mm^2; 218N/mm^2 to 253N/mm^2 ; 188N/mm^2 to 203 N/mm^2 ; 213N/mm^2 to 235N/mm^2 was obtained for samples with 10%, 15%, 20% and 25% additon of GCHA and SDA, respectively as depicted in Figure 3C-F. The implication of the results obtained is that the more the percentage increase in the partial replacement of OPC with GCHA and SDA so also is the decrease in compressive strength.

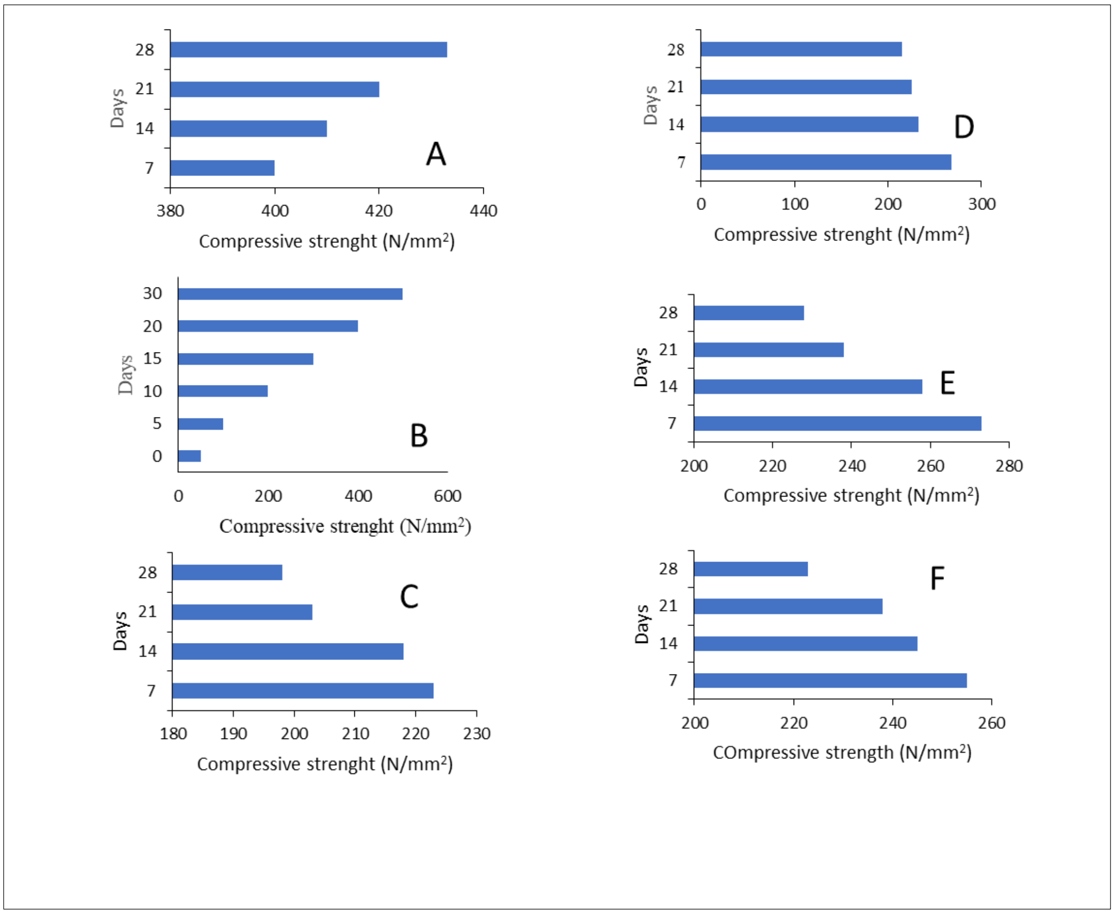

Figure 3 Compressive strength of sample (A) control sample (B) 5% (C) 10% (D) 15% (E) 20% and (F) 25wt% of GCHA and SDA, respectively.

3.3. Splitting Tensile Test of Interlocking Concrete Block

Figure 4 shows the results obtained from the tensile strength tests. The control sample (Figure 4A) cured between 7 to 28 days, has tensilt strenghs ranging from 60N/mm^2 to 73N/mm^2. Meanwhile, samples with 5% blended GCHA and SDA have strenght from 38N/mm^2 to 58N/mm^2 as shown in Figure 4B, while a range of 20N/mm^2 to 40N/mm^2; 35N/mm^2 to 35N/mm^2; 188N/mm^2 to 210 N/mm^2; 25N/mm^2 to 32N/mm^2 was obtained for samples with 10%, 15%, 20% and 25% additon of GCHA and SDA, respectively, as depicted in Figure 4C-F. We infer that, the more the percentage increase in the partial replacement of OPC with GCHA and SDA, the decrease in compressive strength. Consequently, the more the percentage increase in the partial replacement of OPC with GCHA and SDA, the decrease in tensile strength.

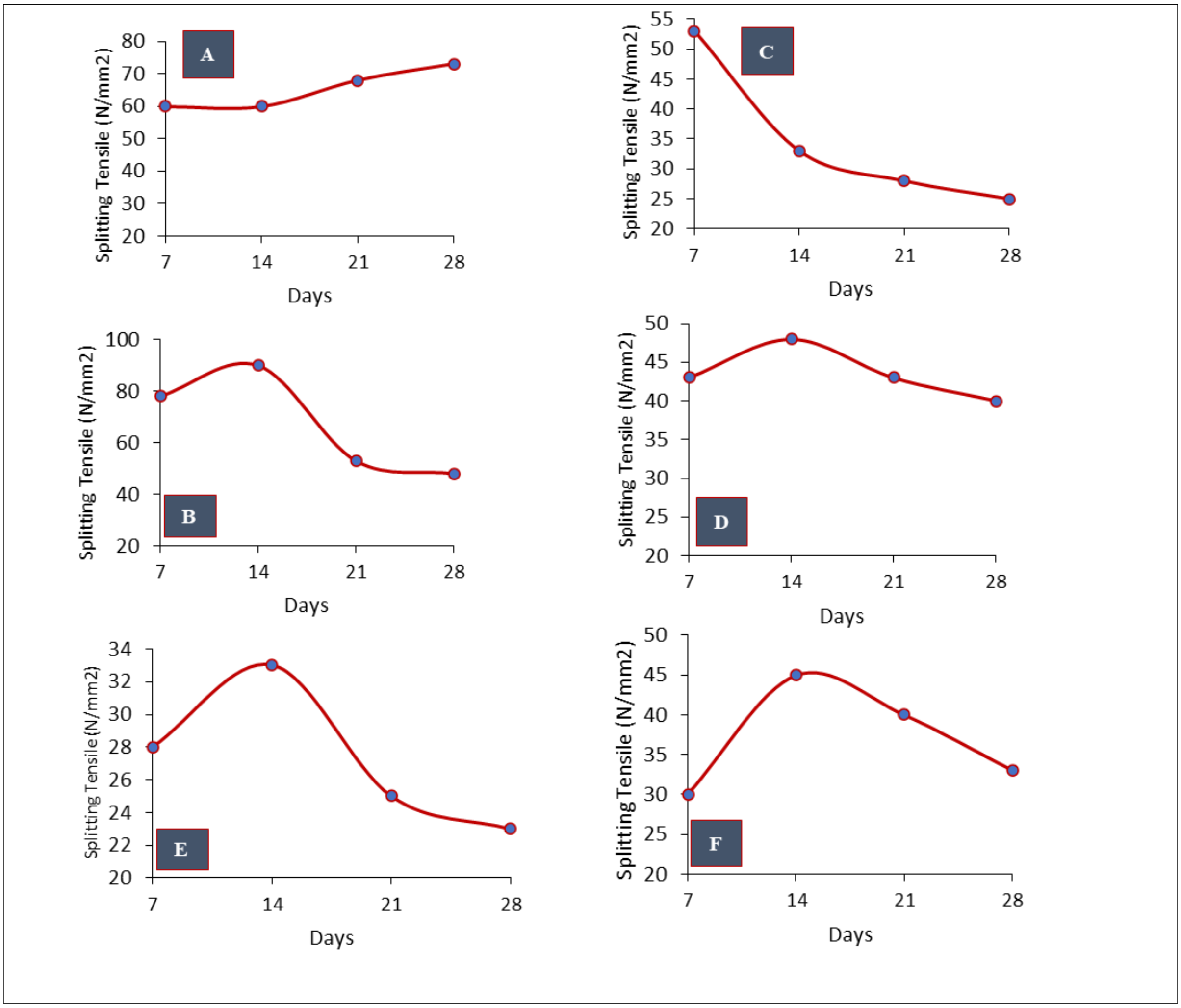

Figure 4 Tensile strength of sample (A) control sample (B) 5% (C) 10% (D) 15% (E) 20% and (F) 25wt% of GCHA and SDA, respectively.

3.4. Water Absorption

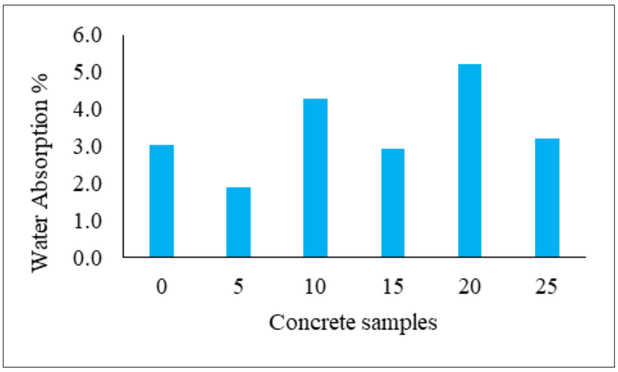

Figure 5 Water absorption of sample with 0 – 25 wt% of GCHA and SDA.

Figure 5A shows the variation of water absorption for the concrete samples. It was observed from the values obtained that control sample i.e. the 0% sample replacement has an absorption of 3%, while 5%, 10%, 15%, 20% and 25% sample replacements have 2.1% , 4.5%, 3.0%, 5.4% and 3.4%, respectively. From the values obtained, it was observed that concrete sample with 20% sample replacement had the highest water absorption of 5.4% and concrete sample 5% replacement had the lowest water absorption of 2.1%. The values obtained from the hardness test are 1.10, 0.51, 0.25, 0.19, 0.17 and 1.31 respectively for 0%, 5%, 10%, 15% , 20% and 25% sample used replacement as shown in Figure 5B below. Therefore, the hardness of the concrete for 5% sample, which has the value of 0.51, has the highest value compared to other sample except for control sample.

3.5. Elemental Composition and SEM/Microscopic Analysis

Results for the EDS are presented in Figure 6. The control sample, shown in Figure 6A reveals that calcium is the major element in the control, with 68.67wt% and other components as trace elements. Meanwhile, samples with 5wt%, 10wt%, 15wt%, 20wt% and 25wt% of blended GCHA and SDA used to partially replace OPC had calcium with values of 59.0, 55.0, 48.0, 46.0 and 40.0wt % respectively shown in Figure 6B-F. The result implies that the more the addition of blend of GCHA and SDA the less the calcium. The result suggests detrimental effects when used in construction.

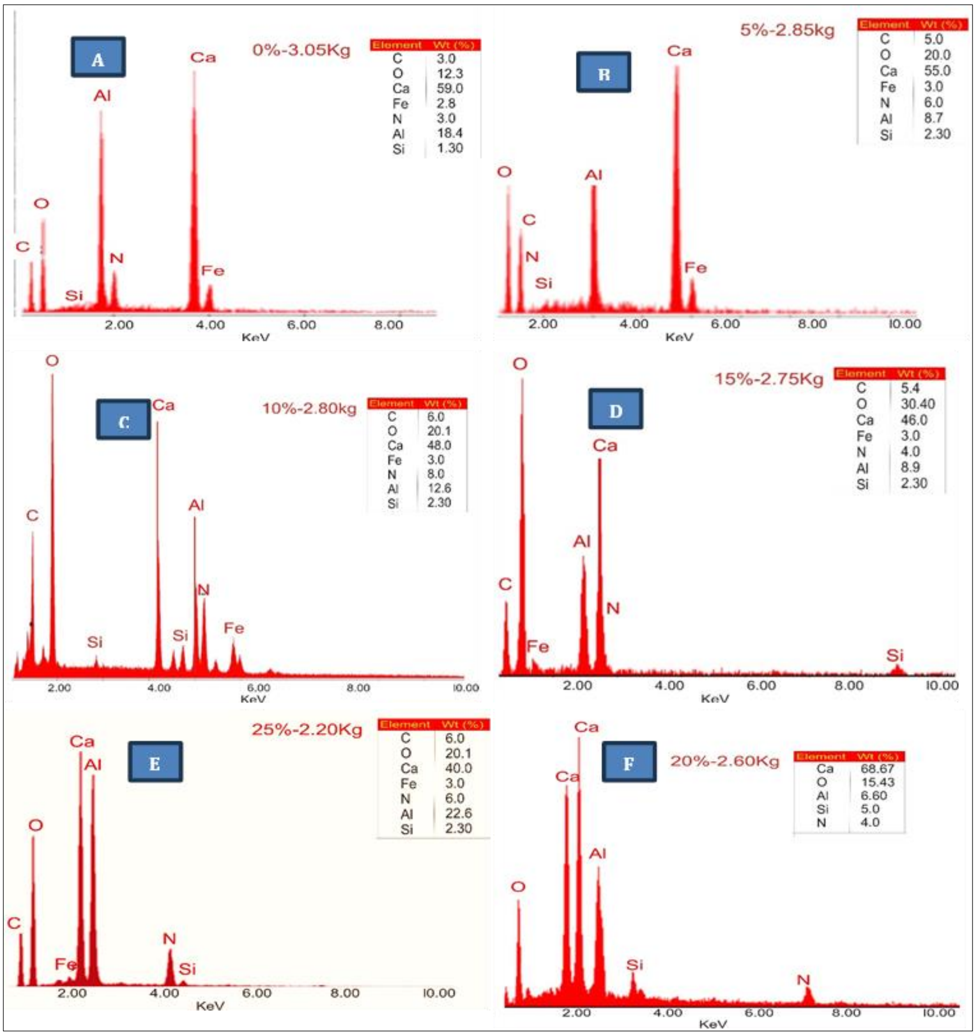

Figure 6 EDS analysis for sample with (A) 0 wt% (B) 5 wt% (C) 10 wt% (D) 15 wt% (E) 20 wt% and (F) 25 wt% of GCHA and SDA, respectively.

Futhermore, SEM was taken for each case at both a lower and higher magnifications (Figure 7) of 26,0000x (left hand side; LHS) and 30000x (right hand side; RHS) respectively. Results show that for the control sample shown in Figure 7A, the mixing degree was fairly distributed with pockets of agglomerations and some pores are visible due to oxide formation. Similarly, at lower and higher magnification of 26,0000x and 30000x respectively, samples with blended GCHA and SDA of 5wt% replacement of OPC as shown in Figure 7B, have uniform distribution of the mixing materials with little agglomeration of residues. Samples with addition of 10wt% of GCHA and SDA indicate a fair distribution from its microscopic analysis but with pocket of agglomeration (Figure 7C). The sample with 15 wt% at different magnification of SEM analysis show not much difference as the particle distribution seems to be uniform all over the surface, shown in Figure 7D. However, at lower magnification of 26000x (left) the particle distribution was good with minor pocket of agglomerations. At higher magnification of 30000x, sample with blended GCHA and SDA of 20wt% shows good mixing degree that led to well distributed particles with little or no pocket of agglomerations (Figure 7E).

Finally, at lower magnification of 26000x for sample with 25 wt%, fair distribution of particles with pockets of agglomeration are observed (Figure 7F; LHS), which are residue during production and can wear off over time leaving the actual surface inlet. However, at higher magnification of 30000x, the mixing degree seems to be better due to particle distribution with more surface becoming visible as shown in Figure 7F (RHS).

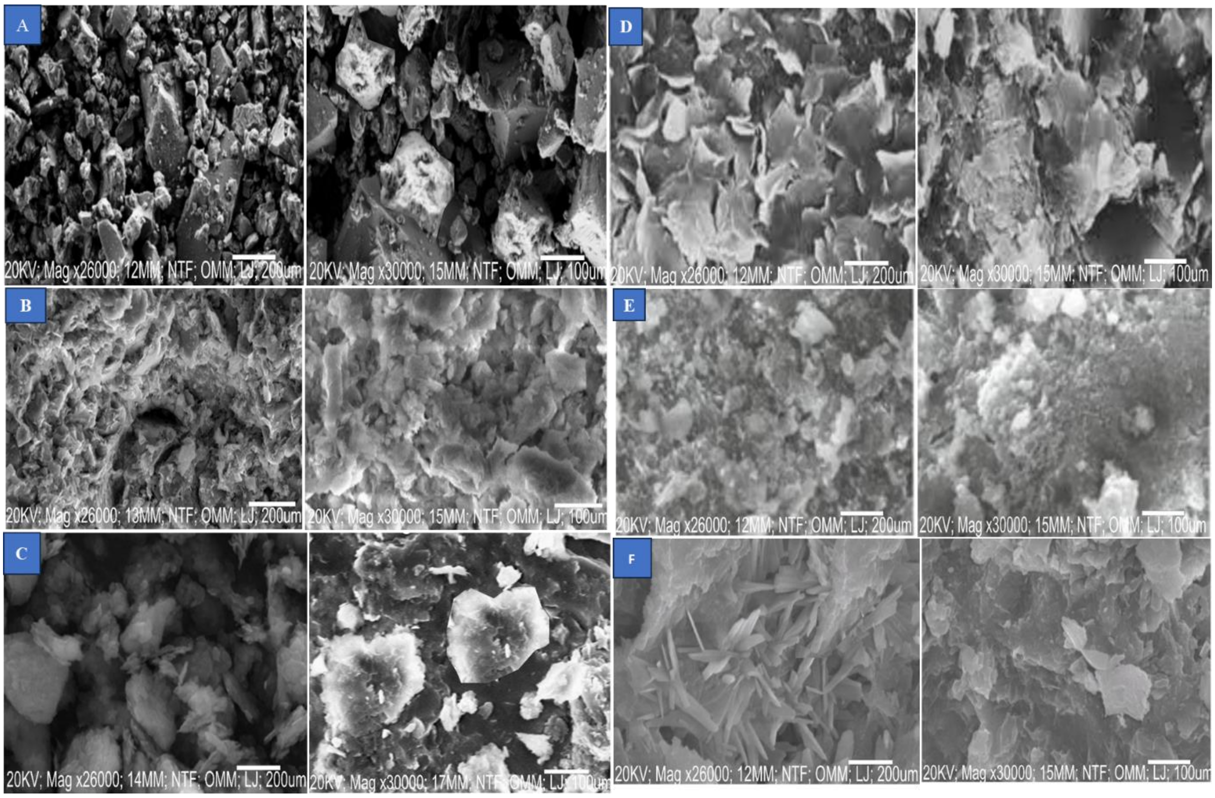

Figure 7 SEM analysis for concrete sample at 26,0000x (left hand side; LHS) and 30000x (right hand side; RHS) with (A) 0 wt% (B) 10 wt% (C) 15 wt.% (D) 20% (E) 25 wt% of GCHA and SDA, respectively.

4. Conclusion

The use of blended GCHA and SDA as a partial replacement of OPC is possible for the construction of interlocking concrete blocking (ICB) which has been analyzed in this investigation. The experimental analysis suggests that the incorporation of the composite ash as partial replacements for Ordinary Portland Cement has both positive and negative implications on the mechanical and microstructural properties of interlocking concrete blocks. While some aspects, such as microstructure density, show potential improvements with increased replacements, the overall trend in higher percentage of the replacement indicates a reduction in compressive and tensile strengths. It should be noted that the characterization and workability of blended GCHA and SDA as a partial replacement of OPC for the construction of interlock concrete block has good workability test between 5-15 wt%, but this percentage is low for super-structure because of the low calcium. Further research will be carried out to refine the combustion process, such as in a temperature-controlled system, to reduce trace elements and enhance the properties of GCHA and SDA. Agricultural waste rich in calcium in equal proportion to the one present in OPC would also be utilized to optimize the current blend.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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