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REUSE OF GLASS AND CLAY BRICK WASTES AS SUBSTITUTE FOR NATURAL AGGREGATE IN GREEN CONCRETE

OLUWAROTIMI OLOFINNADE[1], ANTHONY EDE[1], JULIUS NDAMBUKI[2], and AYANFE OPEYEMI[1]

[1]*Dept of Civil Engineering, Covenant University, Ota, Nigeria*
[2]*Dept of Civil Engineering, Tshwane University of Technology, Pretoria, South Africa*

Utilization of recycled waste materials in making concrete is identified as a sustainable means of managing wastes, thereby reducing the energy consumption, preserving the environment and conserving of natural resources from depletion. Researchers referred to this type of concrete as "green" concrete. This study examines the possible reusing of crushed waste glass as partial and complete substitute for natural aggregates in production of moderate strength green concrete with the addition of ground clay brick as admixture. The clay bricks were obtained as generated wastes from the ceramic and brick producing factory, while the glass wastes were sourced from dump sites and waste collection points within Ota, Nigeria. The waste glass varied from 25% – 100% in steps of 25%, and the ground clay brick was added in 10%, 15% and 20% by mass of Portland cement into the concrete mixes. Tests, which include workability and characteristics strength were carried out on the concrete specimens. Microstructural examination was performed on selected concrete specimens. Results indicate reduction in workability with increased waste glass and clay brick powder content. Moreover, the characteristic compressive strength of the concrete specimens increased with curing age, however, concrete mixes containing 10% clay brick powder and 25% waste glass aggregate showed significant improvement in strength at curing age of 28 days than the control concrete.

Keywords: Compressive strength, Sustainability, Recycling, Eco-concrete, Microstructure, Waste management.

1 INTRODUCTION

The concept of sustainability in the construction industry can be attributed to sustainable development. The report of World commission in Environment and Development on sustainable development mentioned that the idea of sustainable development implies the present generation meeting their needs without compromising the needs of the future generation (WCED 1987). Furthermore, sustainability in the construction industry is now being considered a major concern due to the identifiable environmental impact associated with the amount of natural resource depleted for production of building materials such as cement and concrete for buildings and engineering structures (Bilodeau and Malhotra 2000). The industry is reported to be contributing more CO_2 emission into the atmosphere compare to other industries (Kline and Barcelo 2012). Calkins (2009) mentioned that the construction industry depends more on nonrenewable materials as resources for construction, which in turn aid the destruction of the environment. Of recent, there are continuous research efforts on using the construction industry as a means of managing generated solid wastes. It was reported that the industry provides an effective means of removing large amounts of generated solid wastes from the environment (Calkins 2009, Ling *et al*. 2013). Moreover, over the years there is an increased emphasis on sustainability in the construction industry. That is, limiting the huge impacts of materials on the environment as well as waste materials (Calkins 2009). Some solid waste materials such as waste glass can be reuse and recycled for use in sustainable production of concrete (Siddique 2008, Ali and Al-Tersawy 2012, Tan and Du 2013, Rashad 2014, Olofinnade *et al*. 2017, 2018a). Crushed waste glass was reported to provide an alternative as a substitute material for traditional aggregate in concrete (Rashad 2014, Olofinnade *et al*. 2016a, 2016b, 2018b). However, many studies have pointed out the restraint that is limiting the utilization of waste glass aggregate in concrete. This restraint is referred to as the alkali-silica reaction (ASR) gel formed when the glass material is exposed to attack from the high alkali from the cement paste causing cracking of concrete. Meanwhile, some positive results have pointed out the suppressing effect of ASR through the use of pozzolanic admixtures, low alkali cement in concrete, and lithium compounds (Tan and Du 2013, Carsana *et al*. 2014, Afshinnia and Rangaraju, 2015). The aim of this study is to examine the possibility of using waste glass as a substitute for sand with the addition of clay brick powder as pozzolanic admixture in the production of medium strength green concrete.

2 METHODOLOGY

2.1 Materials: Ordinary Portland Cement

The Ordinary Portland cement used for this study was sourced locally complying with the standard specification of ASTM Type I for cement used for general purpose. Moreover, the chemical constituents of the cement were determined using the X-ray Fluorescence (XRF), and the results are presented in Table 1, including some physical properties of cement.

2.2 Clay Brick Powder (GCB)

The clay bricks were obtained as generated wastes from a ceramic and brick producing factory located within the Lagos metropolis, Nigeria. The bricks were manufactured by calcination of raw clay under high temperature not less than 900 °C. However, before crushing the clay brick wastes into powder, the waste was properly separated to remove unwanted impurities. Thereafter, the wastes bricks were crushed and milled to powder size. The powder specimen was then sieved through the BS mesh 75 μm sieve opening in order to ensure uniform particle size of the same fineness. The chemical compositions of the clay brick powder as shown in Table 1 were obtained using the X-ray Fluorescence (XRF).

2.3 Crushed Waste Glass (CWG)

The glass wastes used in this study were sourced from dump sites and waste collection points within Ota environment, Ogun state. The sourced glass waste debris comprises mainly disposed flat glasses (windows) and container glasses of mixed coloured. After collection of the waste glasses, they were all thorough soaked in water for 48 hours for the purpose of removing unwanted dirt's, contaminants and residues. The waste glasses were then properly washed and openly air-dried. However, due to the nature of glass, safety precaution was taken to protect the hands and eyes by wearing rubber gloves and eye google protection. The waste glasses were crushed to the required particle sizes similar to natural sand. The chemical compositions of the waste glass as shown in Table 1 were determined through X-ray Fluorescence (XRF).

2.4 Natural Fine and Coarse Aggregate

The fine aggregates (river sand) used in this study are sourced locally and commercially. The maximum size of the river sand is 4.75 mm, while that of coarse aggregate (gravel) is 19 mm.

Table 1. Chemical composition of cement, clay brick powder and crushed waste glass materials.

Chemical composition	**Mass (%)**			**Physical properties**			
	Cement	Clay brick powder	Waste glass		cement	Clay brick powder	Waste glass
SiO_2	19.38	60.64	64.31	Specific	3.15	2.52	2.50
Al_2O_3	.00	14.23	19.98	gravity	0.52		
Fe_2O_3	4.14	4.93	6.25	Soundness (%)			
CaO	3.19	0.27	10.61	Setting time	68		
MgO	2.442	1.72	0.63	Initial (min)	473		
SO_3	.00	1.20	0.25	Final (min)		Brownish	Light
K_2O	2.44	1.44	0.74	Colour			grey
Na_2O	1.59	1.94	12.52				
TiO_2	0.21	0.98	0.61				
Cr_2O_3	0.28	0.90					
Na_2Oeq =	0.04						
$Na_2O + 0.658K_2O$	0.02		0.02				
Loss on ignition	0.18		1.47				

Table 2. Proportion of concrete mixtures for this study.

Concrete mixtures		**Binder (kg/m^3)**		**Aggregate (kg/m^3)**				
		Cement	Clay brick powder	Crushed waste glass	Sand	Gravel	Water (kg/m^3)	Water/binder ratio
Control	100%	275	0	0	550	1100	138	0.5
Glass sand-CWG	25%CWG	275	0	138	413	1100	138	0.5
	50%CWG	275	0	275	275	1100	138	0.5
	75%CWG	275	0	413	138	1100	138	0.5
	100%CWG	275	0	550	0	1100	138	0.5
CWG/ 10%GCB	25%CWG	247.5	27.5	138	413	1100	138	0.5
	50%CWG	247.5	27.5	275	275	1100	138	0.5
	75%CWG	247.5	27.5	413	138	1100	138	0.5
	100%CWG	247.5	27.5	550	0	1100	138	0.5
CWG/ 15%GCB	25%CWG	233.75	41.25	138	413	1100	138	0.5
	50%CWG	233.75	41.25	275	275	1100	138	0.5
	75%CWG	233.75	41.25	413	138	1100	138	0.5
	100%CWG	233.75	41.25	550	0	1100	138	0.5
CWG/ 20%GCB	25%CWG	220	55	138	413	1100	138	0.5
	50%CWG	220	55	275	275	1100	138	0.5
	75%CWG	220	55	413	138	1100	138	0.5
	100%CWG	220	55	550	0	1100	138	0.5

2.5 Methods: Mixing Procedures, Casting and Testing of Concrete Specimens

Batching summary for proportioning of the various concrete constituents is presented in Table 2. All mixtures were batched by weight at ratio of 1:2:4 (cement: sand: gravel) to achieve a 28-day strength of 20 MPa. The mixing procedures involve firstly; the sand, waste glass and gravels were admixed together for two (2) minutes. Secondly; cement and clay brick powder used thoroughly mixed together for two (2) minutes, and then added to the aggregate mixture, and all were properly mixed in the dry state for over 5 minutes. Thirdly; the required quantity of water was then added while the mixing process continues for about 15 -18 minutes until a uniform paste was achieved. The slump of the freshly prepared concrete mixes was tested. Concrete cubes specimens were produced using a 150 × 150 × 150 mm dimensions. After curing by total immersion in water, compressive strength of the hardened concrete specimens at the ages of 3, 7 and 28 days were tested (BS EN 12390 2009). Microstructural examination was carried out on selected concrete from the tested concrete specimens.

3 RESULTS AND DISCUSSION

The particle size distribution analysis indicates close similarity for the natural sand and CWG materials. In addition, the workability of the freshly prepare green concrete mix shows a declining trend as the percentage of the glass and GCB increases relative to the control.

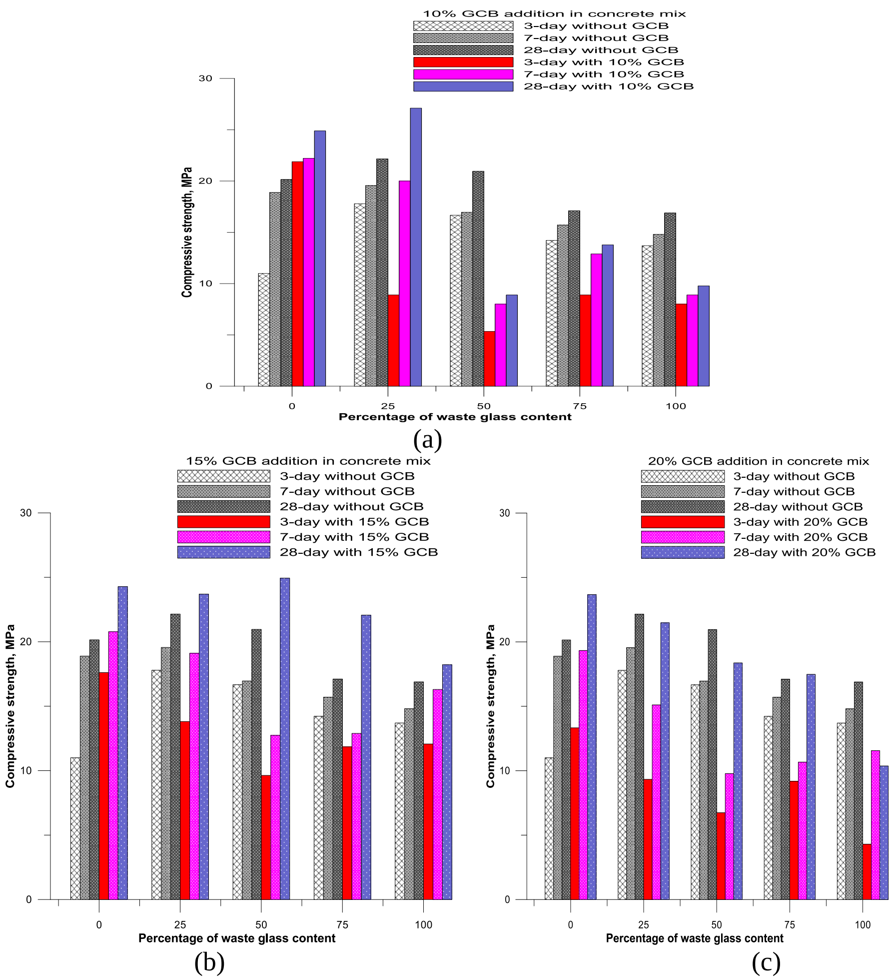

Figure 1. Compressive strength of concrete specimens containing CWG at (a) 10% GCB; (b) 15% GCB; (c) 20% GCB.

Results on the chemical composition of clay brick powder as presented in Table 1 shows that the GCB material can function as pozzolanic substitute for the cement in accordance with the recommendation of ASTM C618 (2003) for pozzolanic material. According to the ASTM C618 specification, that a potential pozzolana should have the additions of SiO_2 + AL_2O_3 + Fe_2O_3 to be minimum of 70% by mass of the chemical compounds. Consequently, for the GCB, the recorded minimum percentage of is 79% by mass. The results on the compressive strength test for the cube specimens are presented in Figures 1 (a – c).

The evolution of compressive strength development for the green concrete containing CWG show a decrease in strength as the CWG contents increases. However, the results clearly indicate that addition of GCB has significant influence on the strength development of the CWG modified green concrete. This can be attributed to the pozzolanic nature of the GCB reacting with the calcium hydroxide $Ca(OH)_2$ from the cement to form a compound of hydrated C-S-H. Moreso, resulting in modification of the green concrete properties resulting in strength enhancement as observed for the 10% GCB addition (He *et al*. 1994, Olofinnade *et al*. 2018a). In addition, it was observed that the compressive strength increases proportionally with the curing ages. Significant improvement in compressive strength was noticed at 10% GCB and 25% waste glass as a partial substitute for cement and natural sand respectively. Figures 2(a – c) depicts the scanning electron microscope (SEM) images taken on the fractured surface of concrete specimens showing pore structure for the control (Figure 2a), containing CWG aggregate (Figure 2b), and a further improved structure with a low number of pores and cracks (Figure 2c).

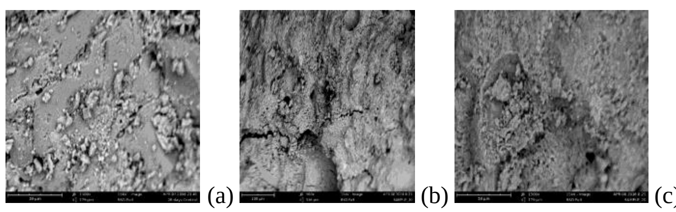

Figure 2. (a) SEM image on control concrete; (b) SEM image on concrete specimen containing CWG particles; (c) SEM image with the addition of GCB.

4 CONCLUSIONS

This study examines the possible production of green concrete using the crushed waste glass and clay brick powder as a substitution material for natural sand and cement respectively. The study shows that the workability of freshly prepared concrete decreases as percentage of CWG and GCB content increases. The addition of GCB into concrete mixes containing CWG improves the compressive strength of the hardened concrete compared to the control. The improvement in strength due to addition of clay brick powder was also corroborated by the microstructure of concrete specimens. Based on findings, crushed waste glass of about 25% replacement for sand with the addition of clay brick powder of about 10% is suggested as a substitute for cement in eco-concrete production.

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