Nigerian Research Journal of Engineering and Environmental Sciences 2(2) 2017 pp. 360-368

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

TOWARDS GREEN CONCRETE FOR SUSTAINABLE DEVELOPMENT BY SUBSTITUTING CEMENT WITH INCINERATED ASH

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ARTICLE INFORMATION

Article history:
Received 17 September, 2017
Revised 05 October, 2017
Accepted 06 October, 2017
Available online 29 December, 2017

Keywords:
Portland cement
Incinerated ash
Compressive strength
Green concrete
Sustainable development

ABSTRACT

A cleaner technology in concrete production involving substituting relatively high percentage of cement by incinerated ash (10%, 20% and 30%) in the concrete mix for higher performance in terms of workability, compressive strength, rate of water absorption and percentage of voids was investigated in this study. The results from the investigation showed that the use of incinerated ash produces concrete with improved strengths at all replacement levels in comparison to ordinary cement concrete. The result also showed that the mix containing 30% incinerated ash gave the best overall performance with less voids, more compactness and lower rate of water absorption. This indicate that concrete incorporating incinerated ash exhibit a better pore structure compared to convectional concrete with cement alone. The durability potential of the concrete investigated containing incinerated ash increased with an increase in the ash up to 30% when compared to the control mix with 100% cement. This indeed suggests a good start in considering green concrete for sustainable development.

1. INTRODUCTION

Color has nothing to do with green concrete. It is a concept of thinking environment into every aspect of the raw materials manufacture over construction, mixture design to structural design, and durability. Green concrete is very often considered to be cheap to produce due to the use of recycled material thereby avoiding the charges for the disposal of wastes well as ensuring less energy consumption and greater durability (Tafheem et al., 2011). While normal construction practices are guided by short term economic considerations, sustainable development in construction for green engineering is focused on best practices which emphasize long term affordability, durability and effectiveness (Bhatia et al., 2016). Any infrastructure designed and constructed in a sustainable way minimizes the use of resources through the whole life cycle of the construction process in which the green concrete play a vital role.

The use of incinerated ash in concrete in optimum proportion has many technical benefits and improves concrete performance in both fresh and hardened state (Luo et al., 2003). The use of incinerated ash in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Generally, incinerated ash benefits concrete by reducing the mixing water requirement and improving the paste flow behavior (Tafheem et al., 2011).

Incinerated ash is a by-product of the steel industry known as blast-furnace slag (BS). It results from the combination of iron ore with limestone flux and is produced in the manufacture of pig iron in a blast furnace. When BS is quenched by water it forms a glassy material known as granulated blast furnace slag (GBS) which when in contact with water possesses hydraulic properties. However, the rate of reaction is slow and needs alkalis and sulphates to activate. As pc hydrates in a mix with GBS, it releases alkalis and sulphates which serve as activators for the GBS (Barnett and Bungey, 2006).

The focus of this study is to report on the material workability, compressive strength, rate of water absorption and porosity of concrete made with incinerated ash. This is an attempt to come up with up-to date information to improve the environmental friendliness of concrete to make it suitable as a green engineering building material for sustainable development.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this research consisted of Portland cement, incinerated ash as granulated blast-furnace slag, natural sea-dredged sand and coarse aggregates.

2.1.1. Portland cement

The Portland cement used for this investigation is of strength class 32.5R in compliance with BS EN 1925: 1999and was supplied by Lafarge Group Plc. The chemical composition of the PC can be seen in Table 1 and the physical properties of the PC in Table 2 (Higgins, 2003).

Table 1: Chemical composition of PC

Oxides	PC
SiO_2	21.0
Al_2O_3	6.0
CaO	66.0
Fe_2O_3	2.0
MgO	4.2
MnO	0.03 – 1.11
K_2O	3.5
Na_2O	1.5
SO_3	3.0
L.O.I	4.9

Table 2: Physical properties of PC

Sample	PC
Median size (mm)	14
Colour	Grey
Bulk density (kg/m^3)	1400

2.1.2. Incinerated ash

The incinerated ash used was Granulated Blast-furnace Slag (GBS) obtained from the Civil and Marine Slag Cement limited Ltd in compliance with BS 6699: 1992. A replacement level of 10%, 20% and 30% was used. The oxide and chemical composition of GBS is shown in Table 3, while the physical properties of the GBS are shown in Table 4 (Yun et al., 2005).

Table 3: Chemical composition of GBS

Oxides	GBS
SiO_2	34.35-35.04
Al_2O_3	11.80-15.26
CaO	36.80-41.40
Fe_2O_3	0.29- 1.40
MgO	6.13-9.10
MnO	0.43
K_2O	0.39
Na_2O	0.34
SO_3	0.05 – 2.43
L.O.I	-

L.O.I - Loss on Ignition

Table 4: Physical properties of GBS

GBS	Sample
Color	Off-white
Bulk density	1200.00 kg/m^3
Blaine fineness	5100 cm^2/kg

2.1.3. Sand

Sand used in this study was natural sea-dredged sand from Bristol Channel (UK) where this study was conducted, and in compliance with mortar composition for fine aggregate (BS EN 197-1:2000, Part 1), with specific gravity of 2.62, fineness modulus of 2.83 and water absorption of 0.82%.

2.1.4. Coarse Aggregates

Coarse aggregate used was medium graded sand combination of 10 mm and 20 mm natural round uncrushed gravel and was made available by a local quarry. It had a specific gravity of 2.73 and water absorption of 1.10%. The rough and angular surface of the 20 mm crushed aggregate gives a good bond and the dust-like particles present in the 10 mm coarse aggregates helps to produce a good density concrete (Oti and Kinuthia, 2008).

2.2 Methods

2.2.1 Mix design, sample preparation and testing of the fresh concrete

The control mix for the concrete in the current research work adopted a mix used on various occasions in a previous study (Oseke, 2017). This mix had been used to assess the Properties of Concrete made with Portland Cement Partly Replaced with Ground Granulated Blast Furnace Slag strength and consistency of concrete . The water to binder ratio used was 0.542 in accordance with (BS EN 197 – 1:2000, Part 1) and (BS EN 1925:1999). The current investigation used GBS to replace the PC in the control mix (M1 - 100% PC) with is . The intention was not to maintain a specified consistency but to obtain a less porous concrete, irrespective of consistency. After several trials with wide range of mixes, four mixes (M2-M4) were selected, Table 5 in which GBS aggregate was used to replace the PC aggregate in the control mix.

Table 5: Fresh concrete mix design

Mix code	Cement (kg/m^3)	Coarse Aggregates: (kg/m^3)		Sand (kg/m^3)	Water (kg/m^3)	GBS (kg/m^3)
		20/10	10/4			
M1	420	210	230	880	189	0
M2	378	210	230	880	189	42
M3	336	210	230	880	189	84
M4	294	210	230	880	189	126

In the first mix using GBS aggregate (M2), the PC aggregate in the control concrete mix was replaced with 10% GBS aggregate. In the second mix (M3), the PC aggregate in the control concrete mix was replaced with 20% GBS aggregate, while the last mix M4 was produced by replacing the PC aggregate in the control concrete mix with 30% GBS aggregate.

2.2.2. Workability of the fresh mortar

The workability test was performed according to procedures established by the British Standard (BS EN 1925: 1999).

2.2.3. Compressive strength tests of the hardened concrete

The compressive strength test at 28 days of curing was determined in accordance with standard procedures (BS EN 1925: 1992). The strength was calculated as follows:

$$\mathrm{Rc} = \frac{F}{A} \tag{1}$$

Where:

Rc = The compressive strength in (N/mm^2)

F = Maximum strength in (N)

A = Cross sectional area of the specimen in (mm^2)

2.2.4. Rate of water absorption tests of the hardened concrete

The water absorption was calculated in order to determine whether there was a decrease in the mortar's pore space as a result of incorporating GBS. This test was carried out after 28 days of curing in accordance with standard procedures (BS EN 1925: 1999). The mortars were immersed in water, at atmospheric pressure until saturation. The percentage water absorption is a measure of the pore volume in hardened concrete occupied by water in saturated condition. It was calculated as a percentage of the saturated mass of the specimen using Equation 2.

$$\mathrm{W_a} = \frac{\mathrm{M_w} - \mathrm{M_d}}{\mathrm{M_d}} \mathrm{x}100\%. \tag{2}$$

Where:

Wa = Water absorption, Mw = Final weight after absorption and Md = Initial dry weight.

2.2.5. Percentage of voids tests of the hardened concrete

The percentage of voids tests were performed in accordance with standard procedures (BS EN6699:1999) in order to determine how much fluid will enter into the mortar through suction forces created by the water molecules and their micro connections with pore walls. The percentage of voids was determined using Equation 3.

$$\text{Voids (\%)} = \left[\frac{B-A}{A}\right] 100 \tag{3}$$

Where:

A = Actual density of the sample, B = Design mix density of concrete.

3. RESULTS AND DISCUSSION

3.1. Workability of Fresh Concrete

The results for workability of fresh concrete measured using slump test are presented in Figure 1. Control mix (M1) yielded a value of 70 mm. Whereas all mixes incorporating GBS (M2 – M4) showed lower slump values. M2, where the PC in the concrete control mix was replaced with 10% GBS showed a marginally lower slump value of 50 mm.

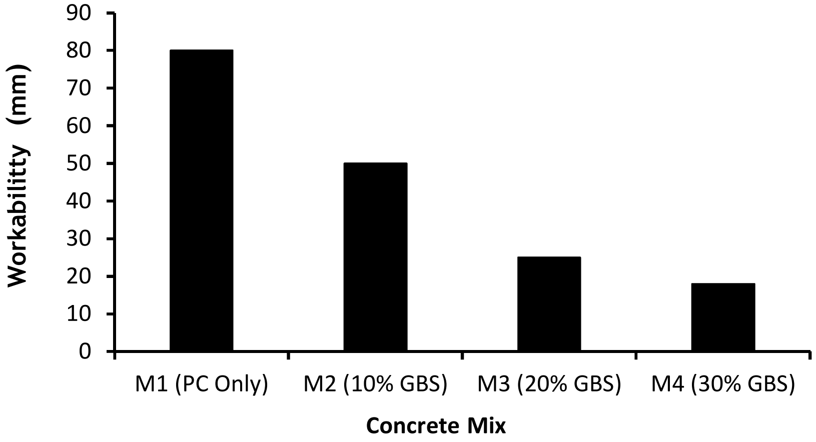

Figure 1: Variation in workability

The observed slump value for mix M3 was 25mm. The slump value for the mix M4 where 30% PC was replaced with GBS aggregate was significantly the lowest (18mm). This decreasing slump values recorded in the mix containing incinerated ash (M2 – M4) is due to the difference in mix compositions, coupled with the varying influence of the differences in particle shape, grading and interlock effect of the ash.

3.2. Compressive Strength

Compressive strength results of the studied concrete are shown in Figure 2. The strengths of the concrete containing GBS were all higher than the control mix (M1) at 7, 14 and 28 days curing ages. The results of this research agreed with conclusions by Luo et al. (2003), who stated that GBS enhances the ultimate compressive strength of the control mix. The results of this research also agreed with those by Belie et al.(1996) who concluded that GBS enhanced concrete produces filler and dispersing effects and increases the nucleation and precipitation site, with enhanced engineering properties when compared with the control Portland cement concrete. The incorporation of GBS also produces the filler effect due to its fine particle size (Naik et al., 2003).

There were variations in the compressive strength of the concrete for the mixtures. This is shown in Figure 2. For the various mixes, the compressive strength at the time of testing appears to increase as the replacement level of GBS increases.

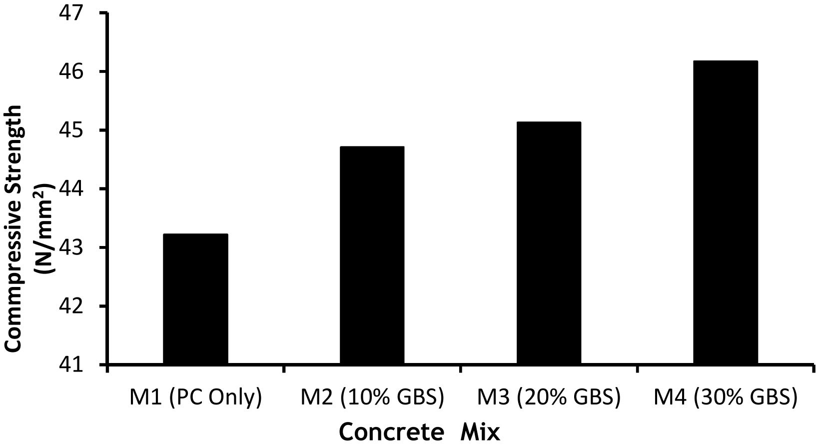

Figure 2: Compressive strength results for the different mixes

The compressive strength of the control mix (MI) was lower than the strength of other mix compositions (M2– M4). The higher magnitude in strength is depended on the distribution of GBS particle sizes within the microstructure. The higher compressive strength in mix (M2-M4) can be attributed to either the gradual continued formation of C–S–H gel within the pore structure, blocking pores and providing strength as the gel develops and ages. [BS EN 197 -1: 2000. Part 1). Compressive strength of a concrete dependent mainly on the type of cement and the type of aggregates in the mortar paste, the cement/aggregate bond (Naik et al., 2003). A good understanding of concrete's compressive strength can assist in the appropriate selection of material to minimize the heat of hydration. This is influenced by the proportion of the calcium silicate hydrates (C_3S) in the cement that causes an increase in the rate of heat of evolution at early age of the hardened concrete. The presence of GBS in all the blended concrete showed positive effect on strength increase up to 28 days, since GBS contains highly reactive siliceous and aluminous materials in a finely divided form. The fines and large surface area allows GBS to be involved more in the hydration process thereby filling the pore spaces left unfilled by the less fine cement particles. The characteristic strength of concrete is based on the 28 days strength test as established by the new European Standard as the minimum for characteristic cubes (Goncalves et al., 2004). The strengths obtained for M1 – M4 were all above the minimum characteristic value cube strength at 28 days curing. Therefore the results are in conformity with the acceptable engineering standard (Siqueira, 2008).

3.3. Rate of Water Absorption

Figure 3 presents the variation of water absorption of hardened concrete with different percentage of GBS. The highest water absorption of curing up to 28 days was recorded for mix M1. The results showed that water absorption rate decreases with increasing percentage of GBS. The higher the GBS content the lower the rate of water absorption as previously observed by Luo et al. (2003.) Increase in water absorption is directly related to the enhancement in pore space in the mortars, thus the greater the increase of water absorption the greater the possibility of early deterioration of the concrete (Mehta, 2000).

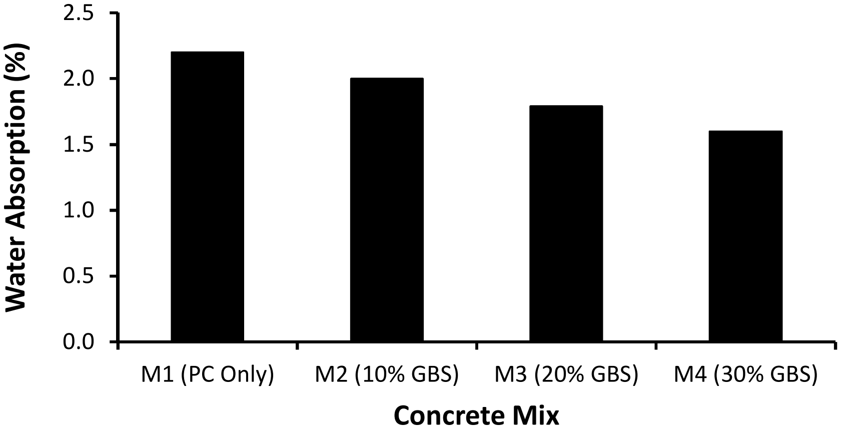

Figure 3: Water absorption of hardened concrete

The level of water absorption is critical when specifying concrete for water infrastructure. High rate of water absorption of concrete material causes swelling of the final concrete resulting in fracture and cracks, while water loss causes the concrete to shrink and will result in loss of strength and low performance over time (Neville, 1996). It is therefore deduced that GBS can be used to improve the water impermeability characteristics of concrete structure, and that the corrosion of reinforcement is retarded and durability of reinforced concrete structure can be increased.

3.4. Percentage of Voids

The results in Figure 4 show that the percentage of voids in the concrete containing GBS M2- M4 are lower than that of the control mix concrete M1 at all ages. The addition of fine particles of GBS causes segmentation of large pores and increases nucleation sites for precipitation of hydration products in cement paste (Naik et al., 2003). This results in pore refinement and a reduction of calcium hydroxide ($Ca(OH)_2$) in the paste as a result of dilution effect. The presence of the ash gives less porous concrete. In other word, GBS is effective in modifying pore and reducing the porosity of concrete. The results generally showed that, the incorporation of 10% to 30% of GBS results in the decrease in void of the internal structure of the concrete, thereby making the concrete less permeable and chemically more stable than convectional PC concrete (Belie et al., 1996). Permeability is the baseline for concrete durability; i.e. a concrete with higher pore structure results in high rate of absorption, producing reduction in durability which can later lead to unbalanced tensile, excessive cracking and water ingress, and finally loss of durability when exposed to harsh environment. (Naik et al., 2003). This findings correlate with the results of Mccloske and Wilson (1997). The main hydration product of PC–GBS based system is calcium silicate hydrates. Additionally, the GBS reacts with the excess of calcium hydroxide to form a finely dispersed gel, which fills the larger pores. The result is a hardened cement paste, containing far fewer calcium hydroxide crystals and therefore has fewer large capillary pores. The reduction in free calcium hydroxide makes the concrete mix chemically more stable, and the finer voids structure (as a result of pore structure refinement) limits the ability of pore development and prevents chemicals diffusing through the concrete surface. Whereas in the case of mix M1, containing PC only, the PC reacts with water and creates insoluble hydration products (mainly calcium silicate hydrates). The more soluble product of hydration (calcium hydroxide) migrates through the voids solution and precipitates as discrete crystals, surrounded by large voids with expansive potential, making the PC based concrete with more pores vulnerable to external attacks (Binici and Aksogan, 2006).

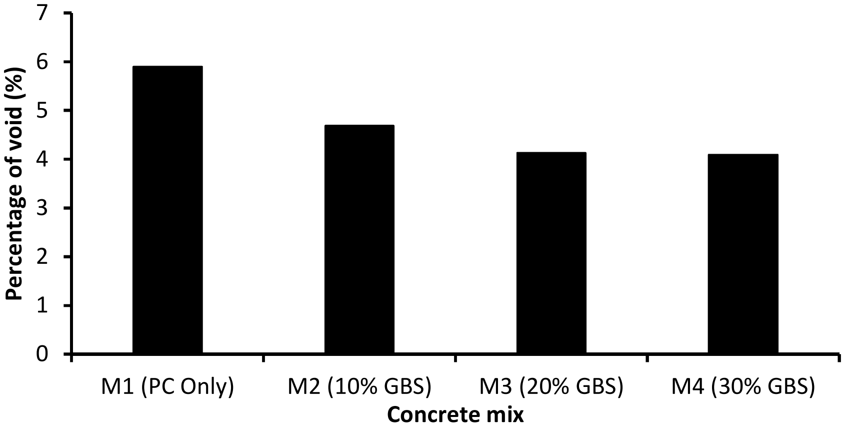

Figure 4: Voids at different curing age

4. CONCLUSION

Green engineering in concrete technology is one of the major steps that a construction industry can implement to achieve sustainable development with various means as discussed. The results obtained in this study suggest that PC composites incorporating GBS are more durable than those made with PC alone, and that durability increased with increasing amounts of GBS. GGBS mixes showed progressive decrease in permeability, water absorption and percentage of voids, thereby making the blended concrete more permeable and dense. This buttress the opinion that there is potential for using incinerated ash (GBS) as partial substitutes for cement replacement that will facilitate more sustainable development in construction technology for green engineering.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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