Open Journal of Engineering Science (OJES)
ISSN: 2734-2115
Article Details:
DOI: 10.52417/ojes.v6i1.786
Article Ref. No.: OJES0601001-786
Volume: 6; Issue: 1, Pages: 01 –14 (2025)
Accepted Date: April10th, 2025

Open Journals Nigeria (OJN)
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www.openjournalsnigeria.org.ng
editorial@openjournalsnigeria.org.ng

RESEARCH ARTICLE **OJES0601001-786**

OPTIMAL CEMENT REPLACEMENT LEVELS IN CONCRETE USING GROUND GRANULATED BLAST FURNACE-SLAG FOR WORKABILITY AND STRENGTH DEVELOPMENT.

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ABSTRACT

Workability and strength development of concrete incorporating Ground Granulated Blast-furnace Slag (GGBS) as partial replacements (10%, 20%, and 30%) for Portland cement (PC) has been investigated. The nature of the components of GGBS has shown a glassy sphere with a composite shell. The form, size, and physical nature of the particles are shown to be the main influences affecting the workability of fresh GGBS concretes and the strength development of the hardened GGBS concrete. The relationship between progressive GGBS particle reaction and strength gain with time has been observed for standard cured concretes up to 28 days. The workability of the concrete was measured by the slump tests. Reductions in the workability were obtained when the mixtures contained 10% GGBS, with greater reductions being experienced as the GGBS replacement level increased up to 30%. Similarly, a relationship between progressive GGBS particle reaction and strength gain with prolonged days of curing time has been observed for standard cured concretes. The early strength development due to the addition of GBBS is largely a beneficial interaction between the normal hydration of cement and the latently hydraulic reaction of GBBS. The study concluded that replacing up to 30% of the optimal replacement of cement in concrete with GGBS could reduce concrete production costs on a project while retaining the acceptable levels of concrete workability and required strength developed.

Keywords: *Concrete, Ground Granulated Blast-furnace Slag Workability, Compressive Strength.*

INTRODUCTION

Partial cement replacement in concrete has become a popular practice and area of study with fly ash being one of the most common replacement materials. The research which focuses on the optimal cement replacement to make concrete greener, extends its key findings to associated areas such as concrete workability and strength development with the addition of cementitious material. Accordingly, Nwofor and Sule, (2012) reported that as early as 1937, it was noted that (GGBS) has been used as a partial cement replacement material for concrete production.

Technology for the utilization of ground granulated blast-furnace slag in concrete is now well-established worldwide (See Figure 1). This process uses considerably less water than granulation techniques. The molten slag is first expanded by treatment with water sprays, and the material is then passed over a rotating finned drum. The semi-molten material is then thrown into the air for cooling and pelletization.

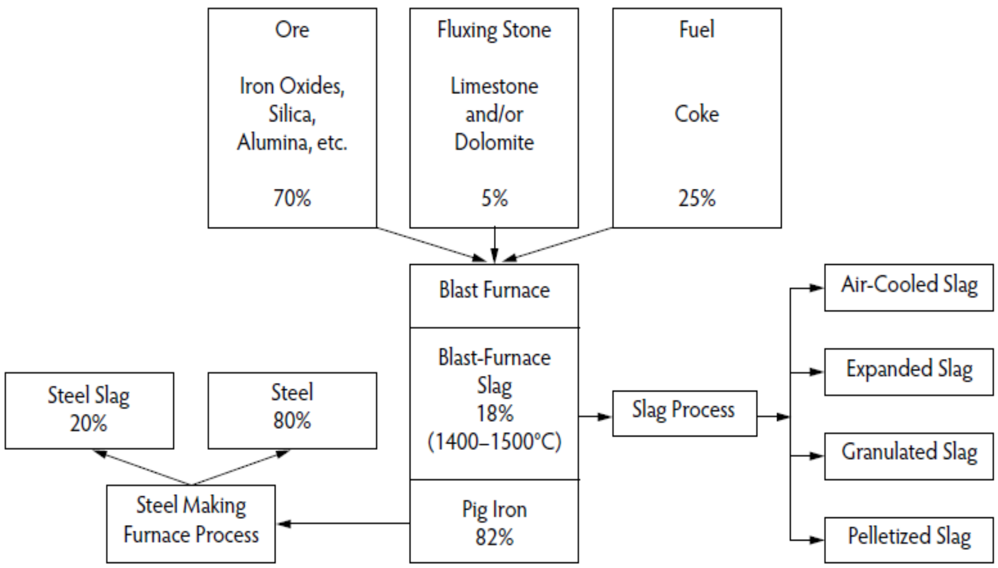

Figure 1*:* Flowchart showing the production of pig iron and GGBS (Taylor, 1997)

The contributions of GGBS in concrete have shown that GGBS interaction with the fresh concrete system is known to be more complex, affecting both the solid and paste phases (Oseke, 2017). These investigations have attempted to define theoretically and experimentally the influence of GGBS on hardened concrete in terms of changes in its theological properties. Importantly, GGBS influences have been identified, such as increased packing density of the solid material and increased paste volume. However, there is no consensus relating the observed effects in concrete with the characteristics of GGBS.

The use of fly ash in concrete has been widely shown to be an effective way to minimize the cost of the concrete using partial cement replacement. The use of GGBS as cement replacement material also improves the performance of concrete that is made with other recycled by-products (Madandoust and Ghavidel, 2013). According to Thomas (2007), the hydration of cement is an exothermic reaction, accompanied by a high amount of heat developed during the reaction. The generated heat causes the temperature to rise and accelerates the setting time and strength gain of cement paste. In many structures, the rapid heat gain of cement increases the chances of thermal cracking, leading to reduced concrete strength development (Shi *et al.,* 2005). The application of high cement replacement levels of GGBS can reduce the damaging effects of thermal cracking (Walker, 2010). The cumulative heat of hydration evolved from a paste containing fly ash remains less than that of cement paste (Ramezanianpour and Jovein, 2011).

According to Shi *et al.,* (2005), the workability of concrete can be increased by the addition of GGBS, while a high level of cement replacement of GGBS can impair the cohesiveness of concrete. However, at optimal replacement levels of GGBS, compressive strength is improved when compared with conventional concrete mix, while replacement beyond optimal levels can lead to deterioration in the properties of concrete with an indication of lower compressive strength. The addition of GGBS up to 10% cement replacement accelerates the compressive strength of self-compacting concrete and establishes a uniform and homogenous mix. Also, the workability of concrete could be increased by the addition of GGBS, while high dosages of GGBS can result in slump loss (Ramezanianpour and Jovein, 2011).

Walker (2010), states that concrete with 10% and 20% replacement of cement with GGBS shows better compressive strength for 14 days curing time than conventional concrete for 0.35 w/c ratio but in 30% replacement of cement scenario with fly ash, compressive strength decreases. In addition, Ramezanianpour and Bahrami, (2012) observed that cement being the most costly component of concrete can be reduced as much as possible by partial replacement of cement with GGBS. Other benefits of partial replacement of concrete with GGBS include lower water demand for similar workability and strength development.

In this regard, this study is aimed at producing a sustainable concrete material with 0.50 w/c that will retain the engineering properties of concrete despite replacing cement with 30% GGBS, while focusing on the workability and strength development.

MATERIALS AND METHODS

CEMENT

The cement used was obtained from a local distributor at Kaduna in Kaduna State and kept in a cool dry place in preparation for use in performing the various laboratory testing. The cement sample satisfies the requirement for use as one of the major components of concrete in that, it was not caked through visual inspection and quick setting time. Table 1 shows the chemical composition of the cement while shown in Table 2 shows the physical properties of the cement used for the study.

Table 1: Chemical Oxide Composition of Cement (Extracted from: Siddique and Klaus, 2009)

Oxide	Cement (%)
CaO	63.000
SiO_2	20.000
Al_2O_3	6.000
MgO	4.210
Fe_2O_3	3.000
MnO	0.030-1.110
SO_3	2.0

Table 2: The Physical Properties of PC (Extracted from: Siddique, and Klaus, 2009)

Description	Physical Properties
Bulk Density	1400.000 (kg/m^3)
Specific Gravity	3.15
Colour	Grey
Insoluble Residue	0.500

FINE AGGREGATE (SAND)

Natural river sand was used as fine aggregate and obtained from a construction site at the National Water Resources Institute Kaduna, Kaduna State. The sand was sieved on a 5.0 mm test sieve to remove larger particles and then air-dried to a saturated state of an aggregate.

WATER

The water sample used for this experiment was tap water collected at the National Water Resources Institute, Kaduna. The water sample passed all the requirements for use based on the fact that it is colorless, devoid of suspended solid particles, and contains an infinitesimal trace of dissolved solid particles with no trace of turbidity after being subjected to laboratory testing. The water was collected in three 4-liter containers.

GROUND GRANULATED BLAST FURNACE SLAG

The slag was obtained from the Civil and Marine Slag Cement Limited Ltd, Newport, UK complying with the (BS EN 12390-6:2000). A replacement level of 10%, 20%, and 30% was used. The chemical oxide composition is shown in Table 3 and the physical properties of GGBS are reported in Table 3.

Table 3: Chemical Oxide Composition of GGBS, (Extracted from: Siddique, and Klaus, 2009).

Oxide	GGBS (%)
CaO	41.990
SiO_2	35.350
Al_2O_3	11.590
MgO	8.040
Fe_2O_3	0.350
MnO	0.450
S^{2-}	1.180
SO_3	0.230

PHYSICAL PROPERTIES OF GGBS

1. The bulk density of GGBS was 1200.00 kg/m$^{3.}$
2. Its Blaine specific surface was 510 m^2/kg.
3. GGBS is usually off-white in colour.
4. GGBS glass content (approximately 90%)
5. GGBS insoluble Residue 0.300%

MIX DESIGN, SAMPLE PREPARATION AND TESTING

The concrete mix design was adopted from previous researches Oseke (2017). However it was modified for the current investigation. Cementing materials comprises of binary mixes of cement and GGBS. The testing was carried out at the National Water Resources Institute's concrete laboratory**.** The samples were prepared in accordance with established practice (BS EN 12390-6:2000). The intention is to maintain a specified consistency and adequate strength developed for application civil in engineering works. Shown in Table 4 is the GGBS mix composition used to replace cement, while the control mix is presented Table 5.

Table 4: Concrete Mix Design with GGBS replacements

Mix Code	Material	Cement (Kg/m^3)	Coarse Aggregates: (kg/m^3)		Sand (kg/m^3)	Water (kg/m^3)	GGBS (kg/m^3)
			20/10	10/4			
BM1	Concrete	420	210	230	880	189	0
BM2	Concrete	378	210	230	880	189	42
BM3	Concrete	336	210	230	880	189	84
BM4	Concrete	294	210	230	880	189	126

Table 5: Design mix with material composition and total production per mix

Mix Title	Material Composition	Number of Cubes	Number of Cylinders
BM1	Aggregates+Sand+Cement	24	2
BM2	Aggregates+Sand+Cement+10%GGBS	24	2
BM3	Aggregates+Sand+Cement+20%GGBS	24	2
BM3	Aggregates+Sand+Cement+30%GGBS	24	2

MATERIALS AND METHOD

WORKABILITY OF FRESH CONCRETE (BS EN 12350-2: 2000)

There are four different test methods used to determine the workability of fresh concrete which include: the slump test, compacting factor test, verbe time test, and flow table test (Oseke, 2017). This study will consider only slump tests, because of their simplicity in type and the ease with which they are carried out in the laboratory

SLUMP TEST (BS EN 12350-2: 2000)

The slump test was carried out to ascertain the workability of the fresh concrete. It is the measure of the workability of the fresh concrete. This test is popular because of the simplicity of the apparatus and procedure**.** Specifications and apparatus size are confirmed according to the (BS EN 12350-2:2009) as shown in Figure 2.

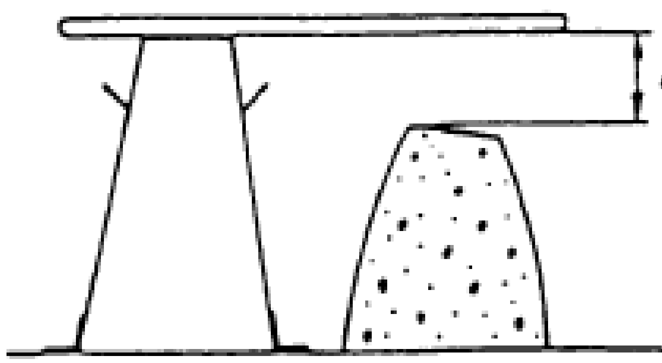

Figure 2: Slump Measurement Apparatus (BS EN 12350-2:2009)

The slump test is simple to carry out and is useful for measuring consistency and detecting variations in uniformity, and measurement is usually carried out immediately after mixing.

STRENGTH DEVELOPMENT OF THE HARDENED CONCRETE

The compressive strength test was carried out on the hardened cured concrete samples. The samples (100mm x 100mm x 100mm Cube Size) were tested following BS EN 12390-3:2009, BS EN 12390 3:2002 specifications with the demonstrative procedure of the samples curing shown in Figure 3. Similarly, the procedure was repeated to determine the splitting tensile strength for the cylindrical specimen (100 mm in Diameter and 200mm) as shown in Figure 4 of the demonstrative procedure of curing. Mathematically, the compressive strength of the concrete cubes was determined using equation (1).

$$Compressive\ Strength = \frac{Failure\ Load\ (KN)}{Area\ of\ Specime(mm^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ (1)$$

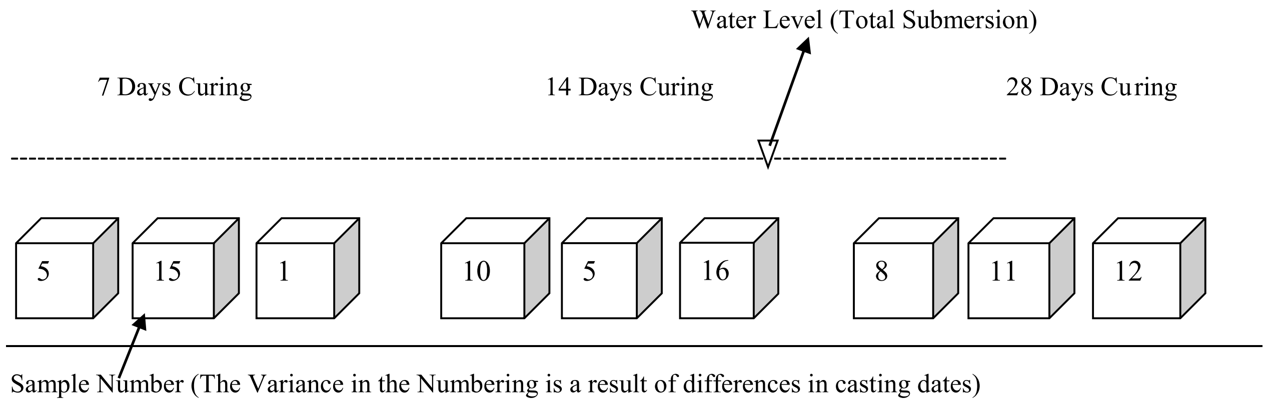

Figure 3: Demonstrative curing process of the cube samples

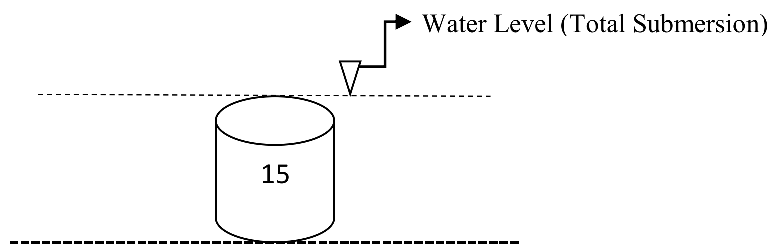

Figure 4: Demonstrative curing process of cylinder sample

RESULTS AND DISCUSSION

WORKABILITY OF THE CONVECTIONAL AND GGBS-BASED FRESH CONCRETE

The workability of the fresh concrete shown in Figure 5, measured using slump test reveals the rate of drop in slump for the target slump for mixes BM2-BM4. The target slump of 80mm was only achieved with the control mix (BM1). It was not possible to achieve this target slump for the mixes containing GGBS. Low slump values were observed for mixes incorporating GGBS (BM2-BM4). The observed slump for mixes BM2 – BM4 was much lower than the target slump (BM1). The slump test was carried out after mixing each concrete batch. It can be observed that the rate of drop in slump was higher in BM4, which has the highest percentage of GGBS (30%). This high drop in mix BM4 was attributed to the large proportion of GGBS incorporated in the mix.

The results also show that the slump decreases with an increase in the percentage of GGBS used, which indicates that more water is required to maintain the same consistency as GGBS content increases. For instance, at 10% -BM2, 20% -BM3, and 30% BM4 GGBS content, there was an observed downward trend in slump values. This implies that GGBS absorbs more water than ordinary Portland cement in a concrete mix designated as BM1. The slump measured for the fresh mix BM1-BM4 is within the recommended value of workability range of ≥10 and ≤210 (BS EN 12350-2:2000) for slump which is suitable for most concrete works. The different classes of slump by the new European Standard (BS EN 206-1:2000) are shown in Table 2.7, where Mix BM1 and BM2 are classified as S2, and mix BM3 and BM4 belong to S1 respectively.

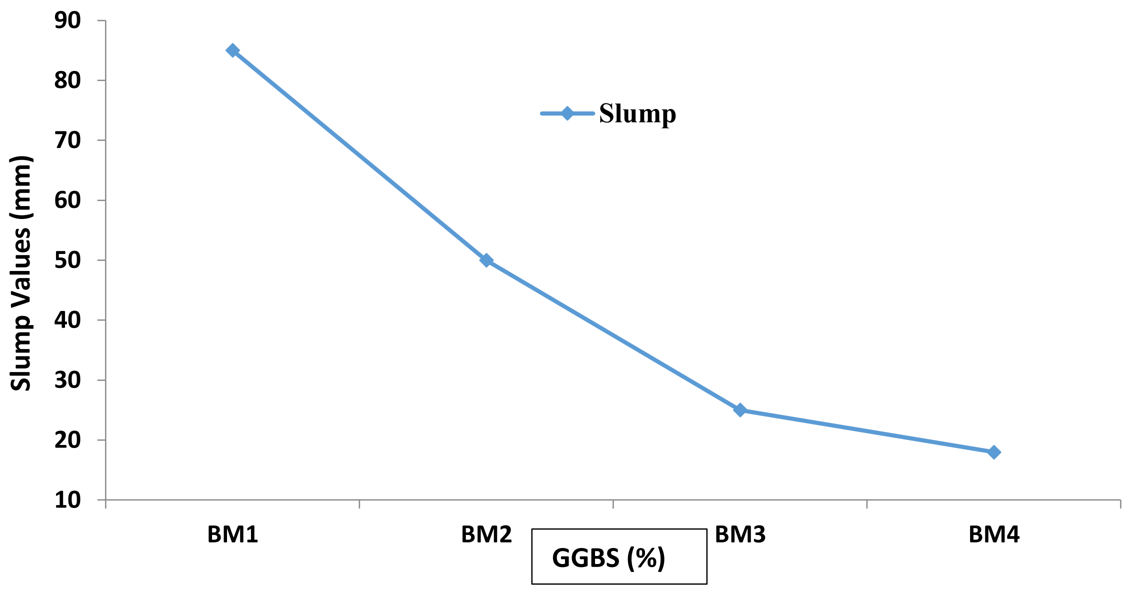

Figure 5: Plot of slump Drop of Various GGBS Content for Workability of the Fresh Concrete

The results of the slump test carried out on the fresh concrete with varying percentages of GGBS as cement replacement are presented in Table 6 corresponding with the corresponding percentage reductions. Higher slump values for concrete produced with GGBS (BM2–BM4) were by far lower than the target slump and that of the control mix (BM1), with no exception. This can be explained in the following manner: the varying values of a slump for the fresh concrete mixes prepared using PC were due to the difference in mix compositions, coupled with the varying influence of the particle shape in GGBS, fines, and its water impeding characteristics. An important point to when GGBS was used in concrete production, the concrete mixtures were observed to be less cohesive during mixing and casting in comparison with the concrete prepared with cement alone. According to Oseke (2017), the lack of cohesiveness of the concrete may have affected the integrity and homogeneity of the fresh concrete during casting as evidenced by varying slump values, which in turn may have affected the strength of the hardened concrete.

Table 6: Slump test result of GGBS-PC blended concrete

Mix Code	Slump	Type of Slump	% Reduction
BM1	85mm	True Slump	Control
BM2	50mm	True Slump	59
BM3	25mm	True Slump	29
BM4	18mm	True Slump	21

Subsequently, the addition of GGBS causes a reduction in workability, which can be attributed to the high levels of coarse and porous residual carbon particles within the GGBS. This, however, would produce a continuous reduction in workability with increasing GGBS content. GGBS has also been shown to accelerate early cement hydration (Amaziah *et al.,* 2013), which could produce a fall in workability due to the more rapid removal of water from the hydration gel and the more rapid production of calcium hydroxide inducing greater flocculation.

According to Amaziah *et al.*, (2013), the effect of GGBS on the workability of concrete is derived from the affinity of the ultrafine negatively charged particles in the GGBS particles onto the surfaces of the positively charged areas on the cement particles. When sufficient numbers of fine GGBS particles are available to completely cover these areas, the cement particles will be effectively dispersed and will flow more easily. Accordingly, an increase in slump may mean that the moisture content of the mix has unexpectedly increased. Alternatively, it can also mean that the grading of the mix has a deficiency in sand content. In general, when a slump is too low or too high, it gives a warning which will enable the mixing technician to take necessary action toward remedying the situation. The various slump classes are presented in Table 7.

Table 7: Slump Class for Workability Application

Class	Slump (mm)
S1	10 to 40
S2	50-90
S3	100-150
S4	160-210
S5	≥220

COMPRESSIVE STRENGTH DEVELOPMENT

The compressive strength test result for strength development is presented in Figures 6, 7, and 8 respectively showing the plots of GGBS-PC concrete and the various percentages of GBBS used to replace PC at 7 days, 14 days, and 28 days curing. It can be seen generally from the figures that compressive strength increases as the percentage of GGBS increases. For instance, the recorded highest 7 days' strength value 33.391N/mm^2 was obtained for mix BM4. Similarly, all the remaining cement replacement levels exhibited a similar pattern of strength loss when compared to the strength of the control mix (BM1). In the 14 and 28-day curing periods, similar strength development was observed as the BM4 strength value in 14 days was 39.39n/mm^2 and 28 Days 43.12N/mm^2 respectively. From all the results presented, it can be observed that higher GGBS additions result in greater compressive strength developed. The higher compressive strength shown by the concrete containing GGBS can also be attributed to the better PC-to-GGBS interlock (interfacial bonding).

According to Balakrishna, and Nataraja (2013), compressive strength depends mainly on the type of cement in the mortar paste and the type of aggregates; the cement/aggregate (fine and Coarse) bond. A good understanding of concrete's compressive strength can assist in the appropriate selection of material to minimize or possibly maximize the heat of hydration, which is influenced by the proportion of the C_3S in the cement that causes an increase in the rate of heat of evolution at early ages of the hardened concrete. This perhaps suggests clearly that the strength development in concrete is influenced considerably by the type of material incorporated in the mix proportion and their hydration process within the microstructure of the concrete. The presence of GGBS contains highly reactive siliceous and aluminous materials in a finely divided form. These materials, in the presence of water, react with calcium hydroxide liberated during the hydration of cement to form compounds (C–S–H gel) possessing cementing properties.

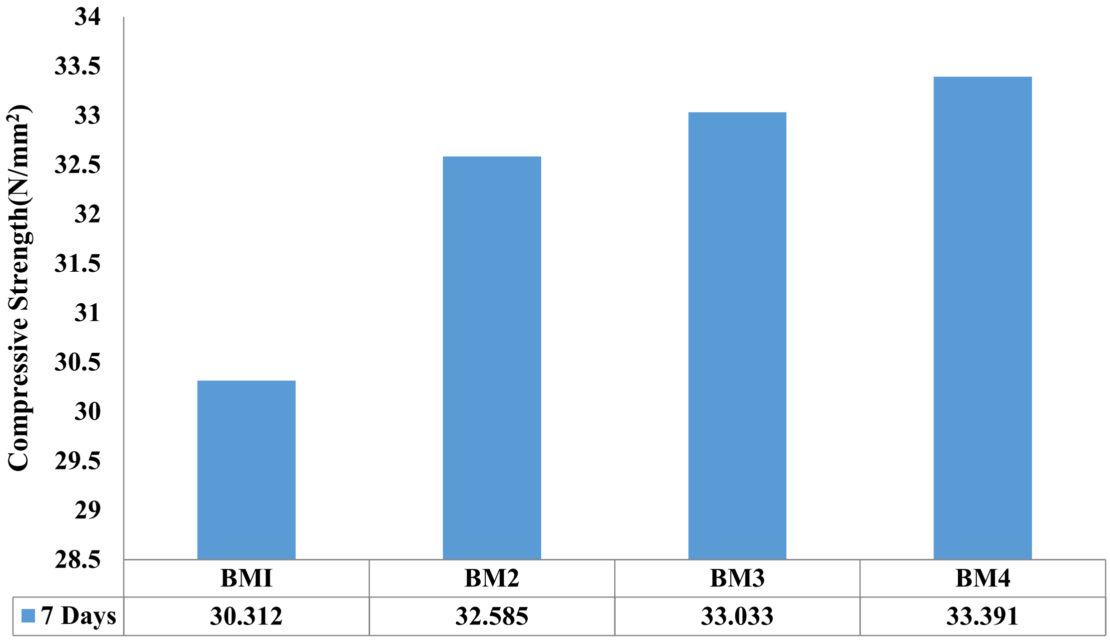

Figure 6: Plot of compressive strength versus age of curing

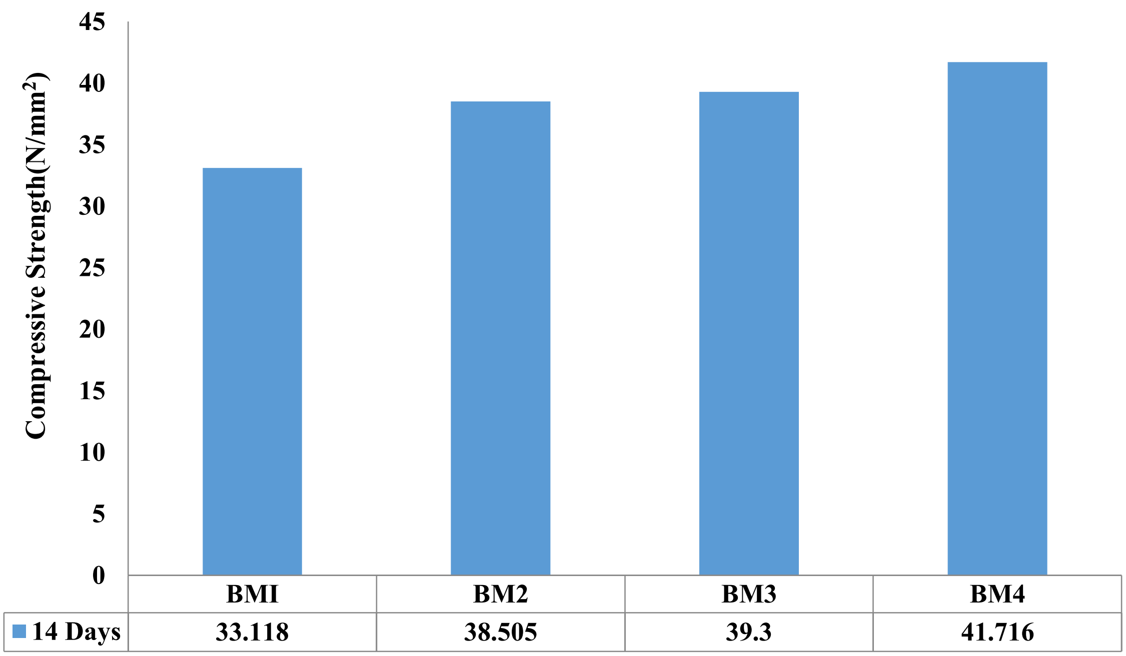

Figure 7: Plot of compressive strength versus age of curing

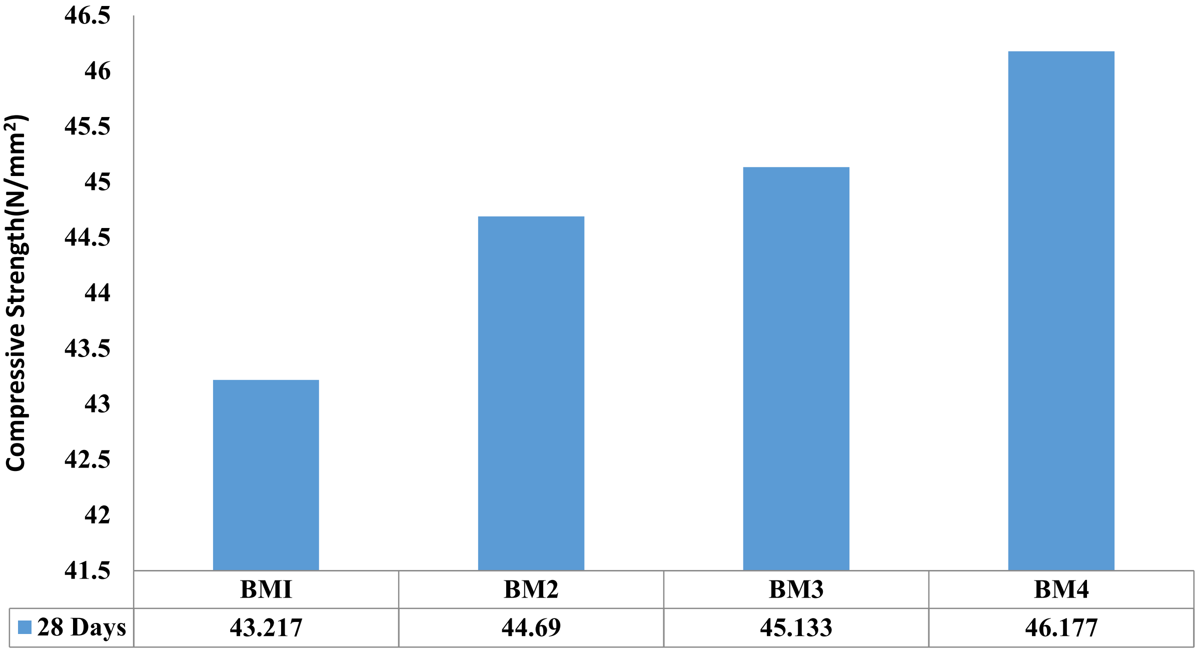

Figure 8: Plot of compressive strength versus age of curing

In addition to this, GGBS contains calcium oxide (CaO) which undergoes a pozzolanic reaction with silica and alumina resulting in gel formation with fines and a large surface area allows the GGBS to be involved more in the hydration process thereby filling the pore spaces which are left unfilled by the less fined cement particles (interfacial chemical reaction). This increases the bonding strength of the matrix, however, low strength may be due to excess GGBS content in the mix proportion. The mineral composition of GGBS is also partially responsible for the highly enhanced strength of GGBS concrete as GGBS includes more SiO_2 and less CaO_3 than PC forming different hydrates in the cement paste (Khimiri *et al.,* 2013).

EFFECT OF GGBS ON THE SPLITTING TENSILE STRENGTH OF THE HARDENED CONCRETE

The plot showing the variation in splitting tensile strength values of mixes BM2-BM4 relative to BM1 is presented in Figure 9 at the end of the 28–day curing period, revealing a downward trend. Furthermore, it can be observed that the drop in splitting tensile strength was greater for mixed BM4. This shows that GGBS-based concrete tended to have lower splitting tensile strength as the GGBS replacement level in the concrete increased from 10% to 30%.

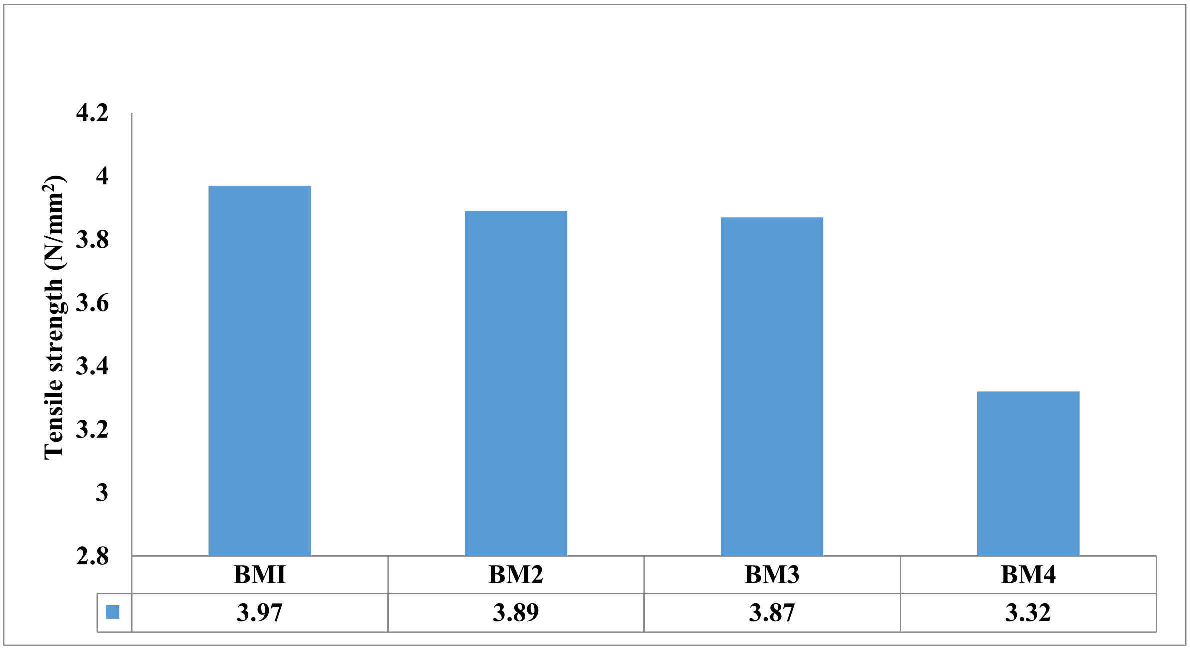

Figure 9: Plot of splitting strength versus age of curing

Tensile splitting strength is an important aspect in engineering design as it can estimate the load under which cracking will develop, and also important in maintaining the continuity of a concrete structure especially in reinforcement concrete against corrosion.

In reinforced concrete, when sharing stress develops, it's a result of diagonal tension which finally leads to cracking of the concrete, as the ability of non-convectional concrete to resist deformation under load is increasingly being highlighted (Amaziah *et al.,* 2013). The absence of cracking is of considerable importance for all engineering works. This indicates that the interface bond strength of cylinders depends on the surface and material characteristics of the concrete composition binding material. The trend can be explained in this manner, where more quantity of PC and less of the cement replacement materials (GGBS) lead to a decrease in the splitting tensile strength of the hardened concrete cylinders, which is a function of the quality of the interfacial zone.

CONCLUSION

Based on the results obtained, the following conclusions were drawn:

1. The workability of PC-GGBS concrete is substantially reduced with an increase in GGBS content. The workability reduction caused by GGBS is attributed to its high chemical activity and high specific surface, resulting in increased water uptake and hence greater water requirement. The workability varied from a high slump value of over 80mm for the control mix (BM1) to a fairly low consistency value of 15mm of concrete (BM4) with a GGBS replacement level up to 30%.
2. The compressive strength of the concrete produced with GGBS in all mixes outperformed that of the control mix (BM1). Subsequently, the tensile splitting strength of the concrete made with GGBS (BM2-

BM4) reduced as the percentage replacement level increased from 10% to 30% up to the age of 28 days of curing leading to the higher strength value observed in the PC-GGBS-based system.

In all, the use of industrial by-product materials such as GGBS is recommended, especially when the materials enhance performance considerably besides the obvious advantages of environmental benefits. This is relevant to civil and construction engineers, as well as to engineering geologists and practitioners working in developing countries, who have to meet global challenges, while faced with increased pressure on transparency, best practices, and the ability to carry out their operations in a more sustainable manner.

CONFLICT-OF-INTEREST DISCLOSURE

The authors declare that there is no conflict of interest as the study was fully designed, implemented, and financed solely by the author.

ACKNOWLEDGEMENTS

The funding body and all those who assisted in the work but may not qualify as an author should be acknowledged. I acknowledge the assistance of the entire staff of the National Water Resources Institute, Kaduna Nigeria.

REFERENCES

Nwofor, T.C., and Sule, S. (2012). Stability of Groundnut Shell Ash (CSA)/Ordinary Portland Cement (OPC) Concrete in Nigeria. *Pelajia Research Library*, **3**(4): 2283-2287

Taylor, H.F.W. (1997). Cement Chemistry, 2nd edition. *Thomas Telford Publishing*, London, pp .43.

Madandoust, R., and Ghavidel, R. (2013). Mechanical Properties of Concrete Containing Waste Glass Powder and Rice Husk Ash. *Journal of Biosystem Engineering*, **6**(11): 113-119

Shi, C., Wu, Y., Riefler, C. and Wang, H. (2005). Characteristics and Pozzolanic reactivity of Glass Powders. *Cement and Concrete Research*, **5**(3): 987-912

Ramezanianpour, A. A., and Jovein, H. (2011). Metakaolin as Supplementary Cementitious Materials on Strength and Durability of Concretes. *Construction and Building Materials*, **30** (28): 470-479

Walker. R. (2010). Mass, Weight, Density or Specific Gravity of water at various temperatures and thermal coefficient of expansion of water, Available online at: http://www.simetric.co.uk/si_water.htm (Accessed: 21 January 2025)

Winter, N. (2005). Understanding Cement, *Concrete strength*, Available online at: http://www.understanding-cement.com/strength.html (Accessed: 20 January 2024)

Ramezanianpour, A. A., and Bahrami, H. (2012). Influence of Metakaolin as supplementary cementing material on strength and durability of concretes. *Construction and Building Materials* **30**. pp 470-479

Siddique, R., and Klaus, J. (2009). Influence of metakaolin on the properties of mortar and concrete: A review. *Applied Clay Science*, **43**(3–4): 392-400.

British Standard Institution, (2000). Testing hardened concrete –part 4, Compressive strength –specification for testing machine. London: *British Standard Institution* (BS EN 12390-4:2000).

Oseke, (2017); Concrete incorporating ground granulated blast-furnace slag, *Nigerian Journal of Scientific Research*, **16**(3):

Amaziah, W. Idongesit, U.D. and Theodore, A. (2013). Exploratory study of crushed periwinkle shell as partial replacement for fine aggregates in concrete. *Journal of Emerging Trends in Engineering and Applied Sciences*, **4(6):** 823-827

Khimiri, A., Chabouni, M. and Samet, B. (2013). Chemical Behavior of Ground Waste Glass when used as Partial Replacement of Cement in Mortars. *Construction and Building Material*s, **4(4):** 74-80

Balakrishna, M.N and M.C. Nataraja, M, C. (2013): Proportioning of Fly Ash Concrete Mixes A Comprehensive Approach, *International Journal of Emerging Science and Engineering*, **1**(8):