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EFFECTS OF SUBSTITUTION OF CEMENT WITH GROUND GRANULATED SLAG ON CONCRETE PRODUCED WITH DIFFERENT WATER-CEMENT RATIOS

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Abstract

Due to growing concerns on the need for alternative material to partially replace cement considering the high cost and environmental problems associated with its production, this study investigated the impacts of fractional substitution of cement with ground granulated steel slag (GGSS) on the features of concrete produced by varying water-cement ratios (w/c). Cement was replaced with GGSS at 0, 10, 20, 30, 40, and 50%. The binder, sand and granite ratio of 1:2:4 as well as the w/c of 0.3, 0.4, 0.5, 0.6, and 0.7 were used. The X-ray fluorescence (XRF) analyser was utilized to ascertain the chemical composition of the GGSS, and its result revealed that GGSS is a class F Pozzolan. The fresh and hardened concretes containing various levels of replacement of cement with GGSS under varying w/c were subjected to workability and various strength tests. Response Surface Method (RSM) was employed for optimum condition analysis that maximized the results of the Compressive Strength (CS), Split Tensile Strength (STS) and Flexural Strength (FS) tests. Findings revealed that concrete becomes more workable with increasing w/c, but declined as the substitution of cement with GGSS increased. The strengths of the concrete declined with increasing w/c; however, the addition of GGSS improved its strength's properties. The optimized 21.57% GGSS substitution for cement with w/c of 0.45 gave maximum value of 25.95 N/mm^2 for CS, 4.24 N/mm^2 for STS and 5.74 N/mm^2 for FS. The comparative cost analysis between the conventional concrete and the optimized OPC-GGSS concrete shows that as much as 11.2% of the concrete constituents' cost can be saved if GGSS is used to substitute OPC in the concrete production. The optimized concrete, which can be utilized as reinforced concrete with improved strength and reduced cost, is therefore recommended for use with the target CS of 25 N/mm^2.

1.0 INTRODUCTION

Cement is a major factor that dictates the cost of concrete as it is many times costlier than other constituents of concrete. The cement manufacturing also causes large emission of carbon-iv-oxide into the atmosphere, which has been a key contributor to greenhouse effects leading to global warming. Therefore, - this has necessitated the ongoing efforts to source for different materials to partially or completely substitute cement in concrete production [1-7]. This search for alternative or supplementary materials for cement would eventually contribute to sustainability and improved waste management systems. At present, the amount of slag being generated is worrisome because it causes serious environmental pollution [8-9]. However, increasing slag application would be a foremost mean of

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resolving these problems. According to Uzondu [10], 0.29 ton of steel slag is obtained in one ton of steel produced and this brings the gross annual estimated iron and steel slag production in Nigeria to about 0.55 million tons.

Elijah [11] also noted that these materials are widely distributed in Nigeria as its industries are thriving in every region of the country, thus bringing Nigeria's combined annual rolling capacity of the mills to approximately 3.50 million tons. Hence, the industrial manufacturing of these materials (steel and iron) is nearly 1.911 million tons annually according to the utilization magnitude of approximately 55% announ-ced by the Central Bank of Nigeria [12]. Steel slags are waste materials produced from the processes of manufacturing steel from iron ore in a Basic Oxygen Furnace or the conversion of fragments to steel through melting in the Electric Arc Furnace.

The key elements and oxides present in slags are silicon oxide, aluminium oxide, calcium, and magnesia that together amounted to over 90% of its overall constituents. The understanding of the chemical, mineralogical and morphological features of steel slag is very crucial because the cementitious and mechanical properties of this material are closely linked to these features. The existing studies [13-15, 54-56] on the substitution of cement with GGSS in concrete production have sparsely considered the impacts of different w/c on various cement and concrete features such as setting times, consistency, workability and strength properties.

Shetty [16] reported that an average of 23% of water to cement weight is needed for chemical activities to materialise with cement blends. Additionally, mixes with low w/c gain strength rapidly than those of concrete with higher w/c. Undoubtedly, this is linked to the cement particles which are closely held together in low water-cement ratio than that of higher w/c [16]. A higher strength and durability is usually associated with lower ratio, but it can make the mix unworkable and difficult to form. The optimization of the amount of water to be mixed with cement determines the strength of concrete [17, 18]. It is also clear that the strength achieved by the concrete is highly impacted by the w/c; hence the need to comprehensively examine the impact of this property becomes paramount [19]. Since the volume of water required in the cement mix affects strength and quality of concrete, it is therefore important that an investigation be carried out to examine the impacts of w/c on the engineering features of GGSS-OPC concrete, which is one of the objectives of this study. This study therefore examined the impacts of the fractional substitutions of ordinary Portland cement (OPC) with GGSS on the properties of concrete produced by varying w/c. The influence of 0-50% GGSS by weight of cement and varying w/c of 0.3-0.7 on the consistency, setting times, slump, compacting factor, CS, STS and FS of the concrete was investigated.

2.0 METHODOLOGY

2.1 Materials

In this research, the materials employed are OPC, sand, granite and GGSS. The cement used for concrete production was the Dangote brand with Grade 32.5R. Clean water that is free from solid matters was used for production of concrete. Concrete was made using crushed stones (granite) and sand having maximum sizes of 12 mm and 5.0 mm, respectively. GGSS was obtained from Iron and Steel Ltd located in Ife, Osun State, Nigeria. The GGSS collected from this company was subjected to sieving process and the sample that passed through BS 75 μm sieve was used to replace cement in certain proportions. Steel slags and granulated steel slag deposit at the company are presented in Figure 1.

Figure 1: Granulated Steel Slag Deposit at Ife Iron and Steel Nig. Ltd

2.2 Experimental Methods

The GGSS, fresh concrete and cured concrete underwent testing for oxide composition, workability, and strength, respectively.

2.2.1 Oxide composition test

The percentage of oxides present in the GGSS was examined using XRF analyser. The test conforms to [20] and [21]. The results of the XRF tests are presented in Table 1. From this Table, the summation of the percentage of Silica, Alumina and Ferric oxide found in GGSS sample is 76.23%, which is higher than 50% specified for class F pozzolan (Table 1). The CaO is lower than maximum of 18% and the loss on ignition of GGSS of 0.002 is also lower than the maximum specification of 6% in [21]. The result indicated that GGSS is a Class F pozzolan. The OPC showed a significantly higher CaO constituent when compared to that of GGSS, however, the percentage of Fe_2O_3 present in cement was much lower compared to that of GGSS. The calcium oxide composition in this study is similar to those reported in existing studies [8, 31-32]. However, the Fe_2O_3 percentage is high, indicating that the GGSS has more iron content than calcium oxide as against OPC, which could result in strong bond formation within the concrete materials because ferric oxide is an important cementing agent [33-34].

Table 1: Oxide composition of OPC and GGSS and chemical requirements for a pozzolan

Oxide composition			Chemical requirements [21]			
Oxides	**GGSS (%)**	**OPC (%)**	**Parameters**	**Class**		
				N	**F**	**C**
SiO_2	33.52	20.09				
Al_2O_3	8.64	4.98	$SiO_2 + Al_2O_3 + Fe_2O_3$	70% min	50% min	50% min
Fe_2O_3	34.07	1.80	CaO	report only	18% max	>18%
CaO	11.96	64.19	SO_3	4% max	5% max	5% max
MgO	-	1.92	Moisture content	3% max	3% max	3% max
K_2O	1.69	0.53	Loss on ignition	10% max	6% max	6% max
MnO	7.85	-				
SO_3	0.33	-				
TiO_2	1.54	-				
P_2O_5	0.48	-				
Loss on ignition	0.002	0.08				
$SiO_2 + Al_2O_3 + Fe_2O_3$	76.23					

2.2.2 Specific gravity and fineness tests

The specific gravity of GGSS, OPC, sand and granite samples were determined using the procedures described in [22] while the initial and final setting times of the GGSS and OPC were obtained in conformity to [23]. This result is similar to those of existing studies [5, 35-38]. The SG values of sand and granite fall within the recommended range of 2.5-3.0 by [39] for average weight aggregate and can therefore be classified as normal weight aggregate. The value obtained for GGSS (2.82) was slightly lower compared to that of OPC (3.06), which could possibly lead to a decline in concrete density. These values are within the permissible limits of Portland cement of 2.30-3.25 specified by relevant standards [52]. Material possessing higher specific gravity is generally accepted as having higher density [16], and based on this, GGSS is of fairly lower density compared to OPC and this could lead to a decrease in self-weight of concrete. The fineness of the OPC and GGSS are 6% and 7.8%, respectively. These values are lower than the maximum of 10% recommended by [53].

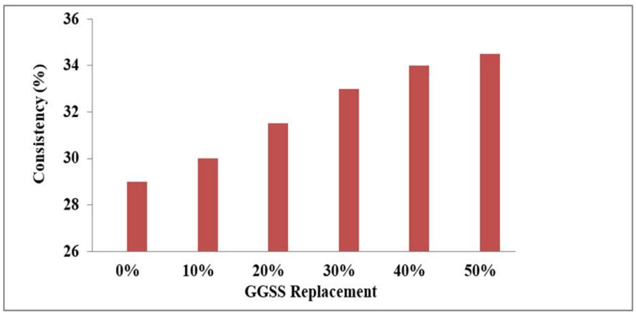

Figure 2a: Influence of GGSS on the consistency of GGSS-OPC blend

2.2.3 Consistency and setting times tests

The consistency and setting times tests were determined for different mixtures of GGSS and OPC in conformity to [23]. The OPC was replaced in the mixtures with GGSS at 0, 10, 20, 30, 40, and 50% by weight of the cement.

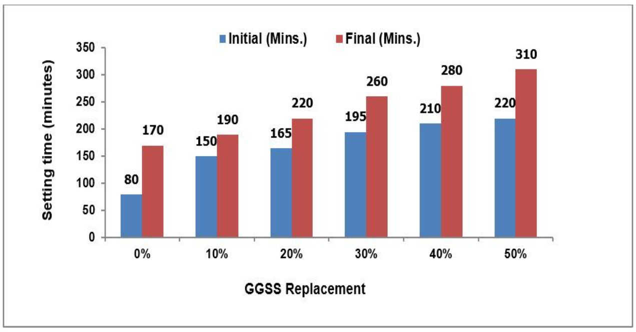

Figure 2b: Influence of GGSS on the setting times of GGSS-OPC blend

Figure 2a shows the variations of standard consistency of different OPC-GGSS mixes while Figure 2b presents the impact of GGSS on the setting times of the fresh GGSS-OPC mix. The results from Figure 2a show that the specimen containing 50% GGSS by weight of OPC has the highest consistency while that of 0% GGSS content showed the least consistency. The consistency of the mortar improved as the substitution of OPC with GGSS increased. The consistency values of the mortar of 29% and 31.5% at 0% and 20% GGSS contents are quite similar to 30% and 33% obtained by [54]. Results from Figure 2b show an increase in setting times (initial and final) with increasing content of GGSS. As recommended by [40], the maximum final and minimum initial setting times should be 375 and 45 minutes, respectively. From the setting time results (Figure 2b), the minimum and maximum initial and final setting times ranged from 80 - 220 minutes and 170 - 310 minutes, respectively. This indicates that all OPC/GGSS samples are within the recommended setting times. The observed trend of these results is also in line with existing works [41-42].

2.2.4 Mix proportions

The OPC was substituted with GGSS at 0, 10, 20, 30, 40 and 50%. The mix ratio of 1:2:4 was used and batched by weight with w/c of 0.3, 0.4, 0.5, 0.6, and 0.7. Total number of 120 concrete cubes of 150 mm sizes, 120 concrete cylinder samples of size 150 x 300 mm and 120 concrete beam samples of size 100 x 100 x 500 mm were produced.

2.2.5 Workability test

Testing for the workability of the various mixtures of the GGSS-OPC fresh concrete was carried out by determining the slump and compacting factors in relation to [24-26].

2.2.6 Concrete strength tests

Experimental tests were also conducted on various GGSS-OPC hardened concrete (cube, cylindrical and beam) samples in order to assess CS, STS and FS of the GGSS-OPC concrete samples, respectively. The concrete samples were cured in tank containing water for 7 and 28 days. These tests were conducted in compliance with the procedures outlined in [27-28, 30].

2.2.7 Statistical and cost analysis

The results of the experimental tests of the CS, STS and FS for the different GGSS-OPC mixtures were subjected to statistical analysis using Response Surface Method (RSM). The numerical optimization function built on Historical Data Design on Design-Expert 7.0 was employed to locate the values of independent variables so as to determine the optimum response values of the concrete strengths (CS, STS and FS). The input parameters were GGSS, w/c and strength (CS, STS and FS) values. To determine these maximum response values of concrete, two factors were selected as: A), w/c (0.3-0.7) and B) GGSS (0-50%) at two levels. RSM was adopted for the optimum condition analysis that optimized CS, STS and FS. The dependent variables are the CS, STS and FS, while the independent variables are the GGSS and w/c. The optimal plots for the response variables are presented in subsequent section. The experimental results were also subjected to statistical evaluation using analysis of variance (ANOVA) so as to assess the significance of the w/c and GGSS on CS, STS and FS. In addition, the cost analysis of the conventional concrete (without GGSS) was carried out by considering the present price of the constituent materials. The cost of conventional concrete was compared to that of the optimum mix (21.57% GGSS and 78.43% OPC at 0.45 w/c) obtained from the statistical analysis to determine cost implication of using GGSS to replace OPC in concrete production.

3.0 RESULTS AND DISCUSSION

3.1 Workability of Fresh OPC-GGSS Concrete

The influence of GGSS and w/c on the workability of the GGSS-OPC concrete is shown in Figures 3 and 4 for slump and compacting factor tests, respectively.

For slump test results, it is observed that as the water content in the GGSS-OPC concrete mix grew, the workability of the concrete mixes increased. However, workability decreased as the substitution of OPC with GGSS increased from 30 to 50% for all w/c. This shows that concrete mixtures require higher water content from 30% GGSS addition upward, indicating greater affinity of GGSS for water than cement. In addition, the higher fineness of GGSS to that of OPC could be responsible for the greater water demand as the GGSS content became higher in the concrete mix [54]. The peak slumps at 10% and 20% GGSS for the w/c of 0.7 could be due to higher water content in both samples, which makes the impact of GGSS to be less significant on the slump, leading to nearly the same values. In addition, looking critically at the slump values for w/c of 0.4, 0.5, and 0.6, it is very clear that slumps only differed with 1 or 2 values, which is not really significant. Zero slumps were obtained for 0.3 w/c at 0%, 40% and 50% GGSS additions.

This technically means low consistency. All the slumps obtained were true slumps except those of 0%, 40% and 50% GGSS substitutions at 0.3 w/c, which gave zero slump due to inadequate water content in the mix. This demonstrates that slump value improved with increasing w/c, boosting the fresh concrete's workability. However, the workability of concrete containing GGSS is quite sensitive to the changes in the water concentration of the mix when compared with concrete made from OPC. The results of compacting factor presented in Figure 4 show similar trend with those of the slump tests. These results also show that as the GGSS contents increased, the compacting factor and w/c also increased. The results obtained are within the specified limit of 0.70 and 0.98 by [25].

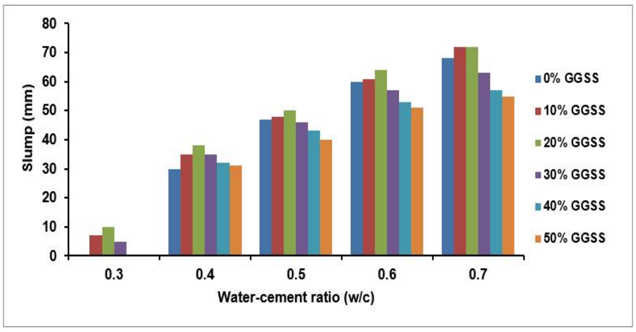

Figure 3: Influence of w/c and GGSS on the slump value of the GGSS-OPC concrete

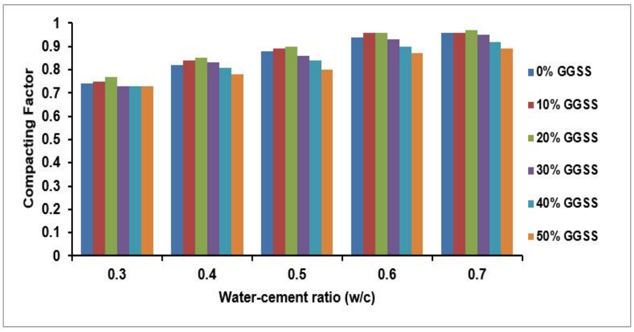

Figure 4: Impact of GGSS and w/c on compacting factor value of the GGSS-OPC concrete

3.2 Comprehensive Strength of Hardened OPC-GGSS Concrete

Figure 5 presents the variations of CS of OPC-GGSS concrete for 7 and 28 days curing periods under various w/c. The results at 7 days indicate that the CS grew as w/c increased from 0.3 to 0.4 but thereafter decreased with a further increase in w/c. This shows that the optimum strength of the concrete mix can be achieved at 0.4 w/c, but further increase of water content reduced the quality of the mix, resulting in decreased strength. Beyond the w/c of 0.4 (7-day curing), the CS values of the hardened concrete decreased with the addition of the GGSS for all w/c. This can be attributed to greater water demand as the GGSS content became higher in the concrete mix, as a result of the higher fineness of the GGSS than cement. [54]. At 28 days, the compressive strength also became enhanced with w/c of 0.4 but decreased in value with higher w/c. However, these values were significantly higher than those of 7 days. Unlike the compressive strength at 7 days which decreased with GGSS addition, the CS at 28th day increased as GGSS increased from 0 to 30%. This increase in strength at 28th day curing could be due to the onset of the pozzolanic reaction (PR) of GGSS in the concrete. This onset of PR led to reduction in the CaOH content while improving densification and strength of the concrete. This reaction eventually resulted in an increase in CS at later curing periods [43]. The philosophy on the progressive unfolding of PR that controls strength development in concrete containing pozzolan is also in consonance with the previous findings by [43-44]. The highest CS was observed for w/c of 0.4 while w/c of 0.3 and 0.7 have the least strength. Normally, concrete with low w/c gives improved concrete strength characteristics while higher w/c will give better consistency but decrease in strength [45-46]. However, at 28 days, the strength of 0.3 w/c showed the lowest strength due to honeycomb which allows voids in the concrete. The CS's behaviour was consistent with the findings of previous studies [14, 47, 54-56]. The maximum strength in this study was obtained at 30% GGSS and 0.4 w/c which negates the 40% reported by [47] and 50% by [45] at 28 days curing age. This variation in maximum strength could be attributed to chemical properties of GGSS obtained from different iron and steel production companies.

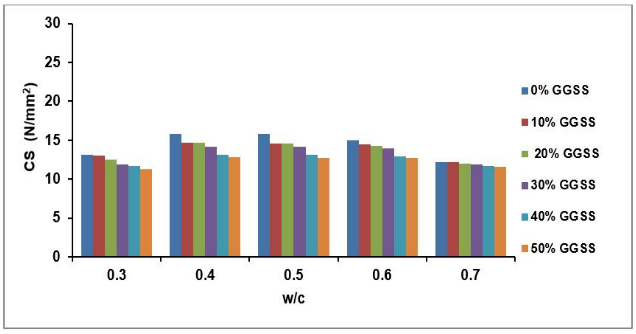

Figure 5a: Variations of compressive strength against w/c and GGSS at 7 days curing period

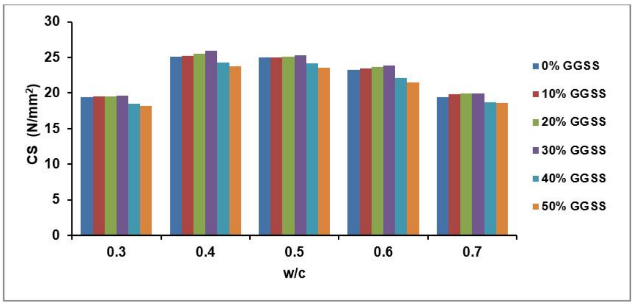

Figure 5b: Variations of compressive strength against w/c and GGSS at 28 days curing period

3.3 Tensile Strength of OPC-GGSS Concrete

Figure 6 presents the variations of STS of OPC-GGSS hardened concrete at 7 and 28 day curing periods under various w/c. The results at 7 days revealed that the STS of OPC-GGSS concrete grew with increasing w/c from 0.3 – 0.4 but reduced with higher w/c.. Similar to the trend observed with CS at 7 days curing, the STS also revealed a consistent reduction in strength with increasing GGSS percentages for w/c of 0.3- 0.7, due to greater water demand as the GGSS content became higher in the concrete mix [54]. The 28th day (Figure 6b) STS also showed a similar trend with the observed results under the CS in terms of w/c but the strength declined after 30% GGSS. The strength of the OPC-GGSS concrete mixtures produced with 0.3 w/c at 28 days also showed the least STS as a result of its low workability and the existence of voids, due to inadequate water content in the mixes. The highest STS was obtained for all mixes at 0.4 w/c, but the strength decreased with further additions of water to the concrete specimens. The behaviour of the STS is also similar to the submissions from [14, 47]. The optimum STS in this study was obtained at 30% GGSS, which did not correspond to 20% reported by [47] and 50% by [45] at curing age of 28 days. This variation in maximum strength could be as a result of GGSS obtained from different iron and steel production company, which could be due to different raw materials involved, burning temperatures and processes of the steel productions [49].

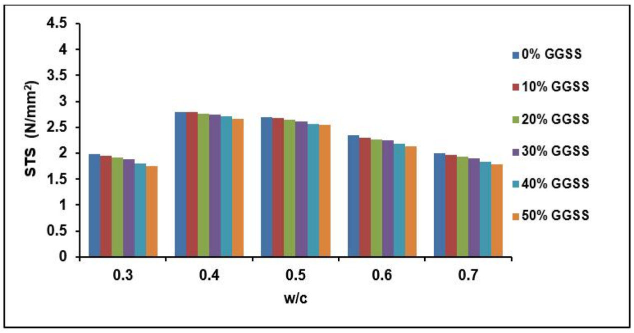

Figure 6a: Variations of STS with w/c and GGSS for 7 days curing age

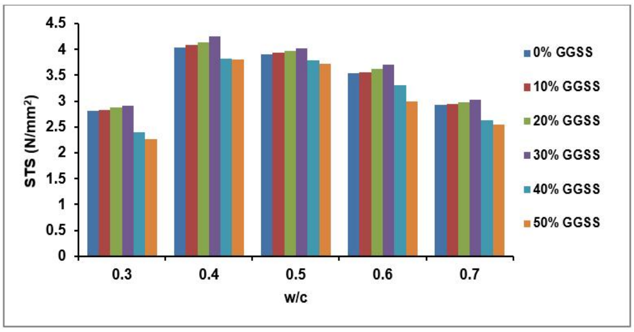

Figure 6b: Variations of STS with w/c and GGSS for 28 days curing age

3.4 Flexural Strength of OPC-GGSS Concrete

Figure 7 presents the variations of FS of OPC-GGSS hardened concrete at 7 and 28 day curing periods under various w/c. At 7 days, the results showed increase in strength as w/c grew from 0.3 - 0.4 but thereafter declined with further increase in w/c. The optimum strength of the OPC-GGSS concrete mix was achieved at 0.4 w/c, but further increment of water content reduced the quality of the mix, thereby resulting in decreased concrete strength. However with increasing GGSS, the FS decreased with increasing contents of GGSS for all w/c. For the 28 days cured specimens, FS reached optimum value at 0.4 w/c but slightly decreased in value with higher w/c. Similar to the trends observed for CS and STS at the 28th day, the FS of GGSS-OPC concrete also revealed a considerable increase in value as the content of GGSS grew from 0 – 30% addition. This increase in strength at 28th day curing may be attributed to the onset of the PR of GGSS in the concrete. The philosophy on the progressive unfolding of PR that controls strength development in concrete containing pozzolan is in agreement with the previous findings by [43-44]. Concrete specimen with w/c of 0.4 gave the highest strength while the least strength values were observed at the w/c of 0.3 and 0.7. This trend of the FS is similar to the findings from [14, 47-48, 54-56]. The optimum FS in this research was attained at 30% GGSS which did not correspond to 35% reported by [14] and 50% by [45] at curing age of 28 days.

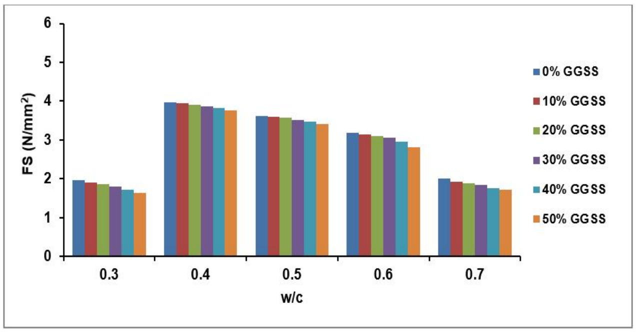

Figure 7a: Variations of FS with w/c and GGSS for 7 days curing period

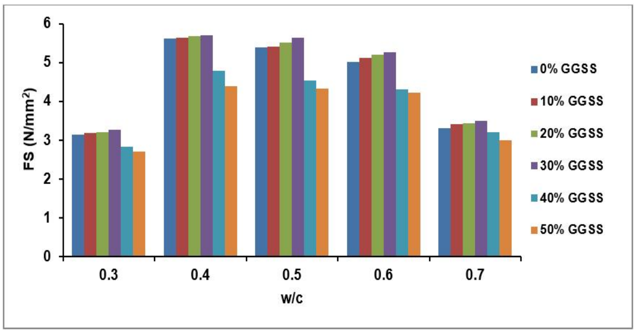

Figure 7b: Variations of FS with w/c and GGSS for 28 days curing period

3.5 Effect of Process Optimization on Hardened Concrete

The effects of process optimization on the CS, STS and FS of the OPC-GGSS concrete at different w/c as determined by the response surface method are presented in Figures 8a, 8b and 8c, respectively. The maximum response value of concrete for the two independent variables; w/c (0.3-0.7) represented by "A" and GGSS represented by B, were determined. The ramp profiles illustrating the desirabilities of concrete as a function of those factors are shown in Figure 9. A desirability of 0.998 for the concrete with a maximum response value of 25.9543 N/mm^2 for CS; 4.23803 N/mm^2 for STS; and 5.74434 N/mm^2 for FS was obtained at A = 0.45 and B = 21.57%. These results showed that optimized values of w/c and percentage of GGSS that gave the maximum CS, STS and FS are 0.45 and 21.57%, respectively. This combination shows higher w/c but lower GGSS content when compared to the 30% GGSS substitution with 0.4w/c observed from Figures 5b, 6b and 7b for CS, STS and FS at 28 days concrete curing, respectively.

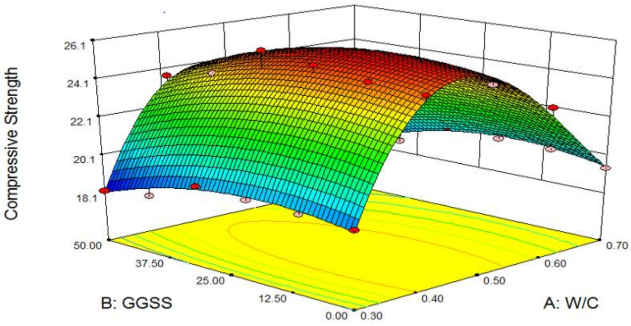

Figure 8a: Effect of W/C and GGSS on CS

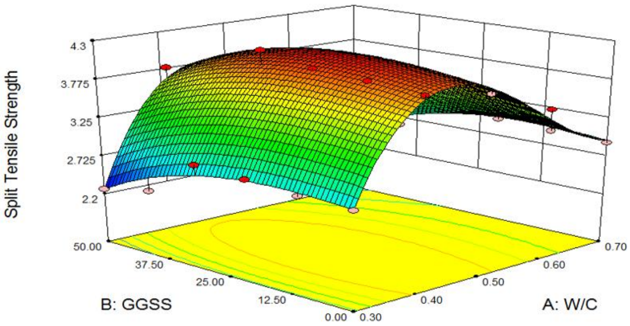

Figure 8b: Effect of W/C and GGSS on STS

ANOVA was also employed at *5%* significance level to assess the accuracy of the model that gives rise to Equations 1, 2 and 3 for GGSS-CS, GGSS-STS, and GGSS-FS, respectively. The ANOVA results of the models are presented in Table 2. From the Table, the Predicted R^2 values of 0.9572, 0.9356 and 0.8907 were observed for CS, STS and FS, respectively. These values agree well with the Adjusted R^2 of 0.9691, 0.9581 and 0.9184. The "Adequate Precision" ratio of 28.345 for CS, 26.810 for STS and 18.950 for FS are higher than 4, which are desirable for the models and indicates an adequate signal [50-51]. As shown in Table 2, the models' F values of 102.06, 74.74 and 35.26 for CS, STS and FS, respectively, were all significant because their equal p-value of 0.0001 is lower than 0.05.

$$CS = 25.62 - 2.66A - 0.75B - 0.019AB - 5.78A^2 - 1.05B^2 + 0.13A^2B - 0.085AB^2 + 2.84A^3 + 0.000B^3 \quad (1)$$

$$STS = 4.13 - 0.79A - 0.062B + 0.014AB - 1.22A^2 - 0.28B^2 - 0.14A^2B + 3.02AB^2 + 0.87A^3 - 0.062B^3 \quad (2)$$

$$FS = 5.66 - 0.64A - 0.63B + 0.065AB - 2.20A^2 - 0.50B^2 + 0.40A^2B + 0.0033AB^2 + 0.76A^3 + 0.039B^3 \quad (3)$$

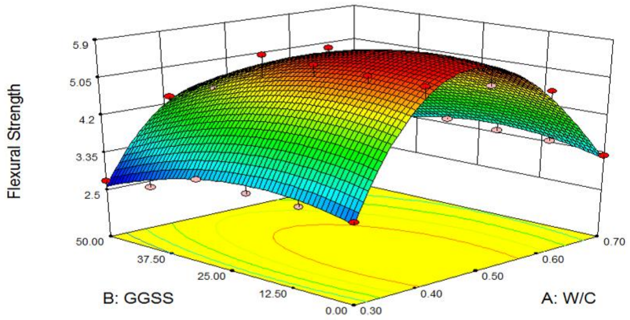

Figure 8c: Effect of W/C and GGSS on FS

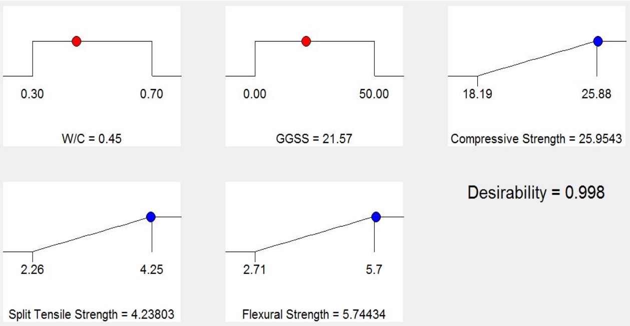

Figure 9: Ramps of hardened concrete under the influence of GGSS

Table 2: ANOVA for OPC-GGSS-Hardened-Concrete

Responses (Strengths)	**Source**	**Sum of square**	***Df***	**Mean square**	***F*-ratio**	***p-value***
Compressive	Model	199.31	9	22.15	102.06	0.0001*
	Residual	4.34	20	0.22		
	Cor total	203.65	29			
R^2 = 0.9787; Adj R^2 = 0.9691; Pred R^2 = 0.9572; Adeq precision = 28.345						
Split Tensile	Model	9.79	9	1.09	74.74	0.0001*
	Residual	0.29	20	0.015		
	Cor total	10.08	29			

	R^2 = 0.9711; Adj R^2 = 0.9581; Pred R^2 = 0.9356; Adeq precision = 26.810					
Flexural	Model	30.09	9	3.34	37.25	0.0001*
	Residual	1.80	20	0.090		
	Cor total	31.89	29			
	R^2 = 0.9437; Adj R^2 = 0.9184; Pred R^2 = 0.8907; Adeq precision = 18.950					

3.6 Cost Analysis

The cost analysis of the conventional concrete (control mix) and that of the optimum mix (78.43% OPC and 21.57% GGSS at 0.45 w/c) of the OPC-GGSS concrete was conducted for the singular goal of comparing the cost. The mix ratio of the concrete used in this study is 1:2:4. The cost analysis of concrete constituents for the two OPC-GGSS mixes is presented in Table 3. The calculation of the cost is based on the average current prices of cement, sand and granite in the South-west region of Nigeria as at 21st June, 2024. The cost of transporting and processing was considered for the steel slag since it was obtained free of charge from the industry. From the table, it can be deduced that the total costs of the concrete constituents per cubic metre are ₦88,440.57 and ₦78,543.23 for the control mix and optimum mix, respectively. This shows that as much as ₦9,897.34 can be saved on one cubic metre of concrete if GGSS is used to substitute OPC, which translates to 11.2% cut in the cost of construction.

Table 3: Cost of concrete constituents for one cubic metre of grade 25 concrete (mix ratio = 1:2:4)

Control mix (conventional concrete)				**Optimum mix**			
Constituent	**Unit rate (₦)**	**Quantity (kg)**	**Amount (₦)**	**Constituent**	**Unit rate (₦)**	**Quantity (kg)**	**Amount (₦)**
OPC	154.00	314.29	48,400.66	OPC	154.00	246.50	37,961.00
GGSS	8.00	0.00	0.00	GGSS	8.00	67.79	542.32
Sand	7.70	628.57	4,839.99	Sand	7.70	628.57	4,839.99
Granite	28.00	1257.14	35,199.92	Granite	28.00	1257.14	35,199.92
Total cost			**88,440.57**				**78,543.23**
Save in cost	$\mathbf{88,440.57 - 78,543.23 = 9,897.34}$						
%age Save in cost	$\mathbf{9,897.34}/_{\mathbf{88,440.57}} \times \mathbf{100} = \mathbf{11.2\%}$						

4.0 CONCLUSION

The listed conclusions were drawn from the experimental and statistical tests carried out in this study:

i. The GGSS possesses higher SiO_2, Al_2O_3, Fe_2O_3 and CaO contents. The summation of Silica, Alumina and ferric oxide is more than 50%. The CaO is also lower than 18%. These conditions indicate that GGSS is a class F pozzolanic material.

ii. The setting times of the OPC/GGSS mix increased with an increase in OPC replacement with GGSS. The setting times observed for all OPC/GGSS samples fall within the required setting times of OPC recommended by ASTM

iii. The mixes of fresh concrete produced from OPC-GGSS became more workable as the water contents in the mix increased, but decreased as the substitution of OPC with GGSS grew from 30 to 50% for w/c of 0.3 - 0.7. The observed trend of the compacting factor test is also similar to slump test result.

iv. The compressive, split tensile and flexural strengths reduced as w/c increased from 0.4 - 0.7. However, addition of GGSS up to 30% by weight of OPC enhanced the CS, STS and FS of hardened concrete. Water cement ratio of 0.4 has the highest CS while w/c of 0.3 has the least strength.

v. An optimized 21.57% GGSS substitution for cement with w/c of 0.45; which gave maximum value of 25.95 N/mm^2 for CS, 4.24 N/mm^2 for STS and 5.74 N/mm^2 for FS; is recommended for use in ratio 1:2:4 concrete with the target CS of 25 N/mm^2. The comparative cost analysis between the conventional concrete and the optimized OPC-GGSS concrete shows that as much as 11.2% of the construction cost can be saved on one cubic metre of concrete if GGSS is used to substitute OPC in concrete production. The concrete produced with this GGSS can be utilized as reinforced concrete with improved strength properties and at reduced cost. In addition, application of GGSS in concrete production will consequently reduce the environmental pollution and other societal problems associated with the disposal of steel slag in the environment.

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