International Conference of Science, Engineering & Environmental Technology (ICONSEET), 2(30): 229-235, 2017
ISSN 0794-9650
www.repcomseet.com

Effects of Blast Furnace Slag as a Partial Replacement for Cement in Concrete

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Abstract – The use of blast furnace slag in civil engineering researches is becoming more popular because of its availability cum performance. This study investigates the potential use of blast furnace slag as a partial replacement for cement in the production of concrete. After batching, 1:1½:3 mix of concrete was produced in varying slag proportions of 5%, 10%, 15% and 20% by weight of cement. Findings revealed that the slag-blended concrete which was produced at the chosen water-cement ratio of 0.5 has low workability compared to the conventional concrete. Method of curing by shading was adopted and the compressive strength of slag-blended concrete with varying slag proportions of 5%, 10%, 15% and 20% at 28days of curing was found to be 11.48N/mm^2, 17.98N/mm^2, 18.19N/mm^2, and 20.87N/mm^2 respectively. There are significant differences between the compressive strength values obtained and this actually justifies the use of the blast furnace slag in concrete production.

Keywords: Partial Replacement, Performance, Significant, Slag, Compressive Strength, Workability.

1. Introduction

Blast furnace slag according to KWah (n.d.) is simply described as the byproduct of steel industry whose typical composition includes Silica (30-40%), Lime (35-45%) and Alumina (10-20%) and it enhances concrete durability and typically replaces 60-70% of cement amongst other benefits. The use of blast furnace slag as aggregates in concrete has been a promising concept in civil engineering researches. It has been confirmed that usage of industrial byproducts, in general, promotes sustainable development and it is therefore pertinent to resort to the utilization of by-products as admixtures in concrete in order to accomplish an improved concrete proper performance at reduced cost. LaBarca et al. (2007) in their research work examined the feasibility of using grade 120 slag cement as a substitute for Ordinary Portland Cement (OPC) at replacement levels up to 50% by mass. Strength and deicer scaling resistance properties were studied for concrete incorporating grade 120 slag cement at 0%, 30%, and 50% replacement levels.

It was determined that grade 120 slag cement replacement up to and including 50% is acceptable when the mixing and curing temperature is greater than 40°F. Grade 120 slag cement concrete mixed and cured at 40°F did not gain strength quickly enough in the laboratory to conclude that roadways may be opened to traffic in an acceptable amount of time. Similarly, in the work of Richardson (2006), it was found that slag proportions of 40 to 60 % appear to be the optimum level for highest strength development. But Singh (n.d.) establishes that the compressive strength of 100% blast furnace slag concrete was found to be increased up to 2.8% in comparison to conventional concrete. The study shows that the use of blast furnace slag aggregates not only as substitute for stone aggregate but also increases the strength of concrete. Hiraskar and Patil (2013) have already confirmed that Blast Furnace Slag (BFS) has properties similar to natural aggregates which would not cause any harm if incorporated into concrete.

The research showed that using blast furnace slag as coarse aggregates in concrete has no negative effects on the short term properties of hardened concrete while Correia (n.d.) posits that the addition of Ground Granular Blast Furnace Slag (GGBS) in concrete significantly improves the resistance against chloride ingress, when compared to Portland cement concrete and it was also established that GGBS concrete outperforms Portland cement concrete at all ages, and all percentages of replacement, even if the slag replaces the cement on a one-to-one basis. Yatagai et al. (n.d.) states that when the cement with high C_3S content was used, the water content required to obtain the specified slump was decreased by using blast-furnace slag down to the same level as that of Ordinary Portland.

Early-age compressive strength of concrete with blast-furnace slag cement type A was improved by increasing C_3S content more than 65%, especially at low temperature. Various effects of Blast Furnace Slag in concrete production are reiterated by Kim et al. (2016) in which as the replacement rate of blast-furnace slag aggregates increased, the void ratio increased. This phenomenon occurs because the void ratio of blast-furnace slag aggregates is greater than that of natural aggregates. However, Karri et al. (2015) examined the effects of HCl and H_2SO_4 on GGBS concrete. It was also evident in their work that the effect of HCl on strength of the concrete is lower than the effect of H_2SO_4 on strength of the concrete. And when blast furnace slag is used partly as a binder in concrete (as submitted by Jariyathitipong et al. (n.d.)), it improves the resistance of concrete to chloride ions and sulfate attack. The aim of this research work is to determine the effects of blast furnace slag as a partial replacement for cement in concrete.

2. Materials and Methods

2.1 Materials and Equipment Used for the Study

Materials utilised for the study include Ordinary Portland Cement (OPC), Sand (consisting of hard, durable, uncoated inert particles, reasonably free from organic substances of 3.65mm size and obtained from Agbale road, Ede, Osun State), Granite (consisting of hard, durable, uncoated inert particles, reasonably free from organic substances of 19mm size), Potable water free of impurities and Blast Furnace Slag (BFS) obtained from Prism Steel Mills Limited, Ikirun Osun State (as shown in Figure 1). The BFS was used in its powdered form passing through Sieve size 600 microns. It was used in varying percentages of 0%, 5%, 10%, 15%, and 20% as a partial replacement for cement in concrete. The apparatus and equipment used in the study include the metal moulds (with internal dimension of 150mm x150mm x150mm), Set of BS sieves, Trowel, Tamping rod, weighing balance, and Compression testing machine.

Figure 1: Blast Furnace Slag Samples

2.2 Experimental Procedure

Batching and Mixing

The method of batching by weight was used and 1:1½:3 mix was adopted as proportions of cement, sand (sharp sand), coarse aggregate (granite), and blast furnace slag (as partial replacement for cement in varying proportions of 0%, 5%, 10%, 15% and 20%) were batched manually. The materials were thoroughly and uniformly mixed together using shovel and 0.5 water-cement ratio was adopted.

Sampling

Moulds were cleaned, lubricated and filled with concrete in three layers of approximately 50 mm thick. Each layer was compacted with 25 strokes using a tamping rod and the top surface was levelled and smoothened with a trowel. 3 specimens of concrete cubes were cast for each batch.

Curing

After casting, the concrete cubes were left in the laboratory at room temperature for 24 hours after which the cubes were marked, demoulded and cured using shading method for 7, 14, 21 and 28 days.

Determination of Chemical Composition of Steel Slag

The chemical compositions of the steel slag and its nature were determined using X-ray fluorescence spectrometer and X-ray diffraction spectrometer. The sample was analysed at the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife.

Determination of workability of concrete

The workability test was carried out by slump test which was performed in accordance with BS1881 and the workability was determined through slump test and compaction factor test.

Determination of compressive strength of concrete

The concrete cubes (after being cured through air for 7, 14, 21 and 28 days) were placed in the compressive machine and load was then applied gradually without shock till the concrete cubes failed as shown in Figure 2, the maximum load was recorded and any unusual features in the type of failure was noted.

Figure 2: Concrete cube under compressive failure

3. Results and discussion

Compressive strength of the concrete

The compressive strength of the cube specimen was calculated by dividing the maximum load at which the specimen fails by the cross sectional area. Average values of the three cube samples crushed at each age of curing were taken as the representative value. The compressive strength values are represented in Table 1 while it was evident from Figure 3 that the Blast Furnace Slag has significant effect on the compressive strength of concrete as the strength of the concrete increases in relation to increase in proportion of BFS.

Table 1: Compressive Strength Values

Age of Curing	7 days	14 days	21 days	28 days
0% BFS	9.99	10.67	11.02	12.50
5% BFS	7.59	8.68	9.66	11.48
10% BFS	9.87	12.71	13.54	17.98
15% BFS	11.38	14.34	15.43	18.19
20% BFS	13.92	16.00	17.48	20.87

Workability of the concrete

Both the slump test and the compaction factor test (represented in Figures 4 and 5) confirm that the slag–blended concrete has a low workability while the conventional concrete has a high workability at the water - cement ratio of 0.5 chosen.

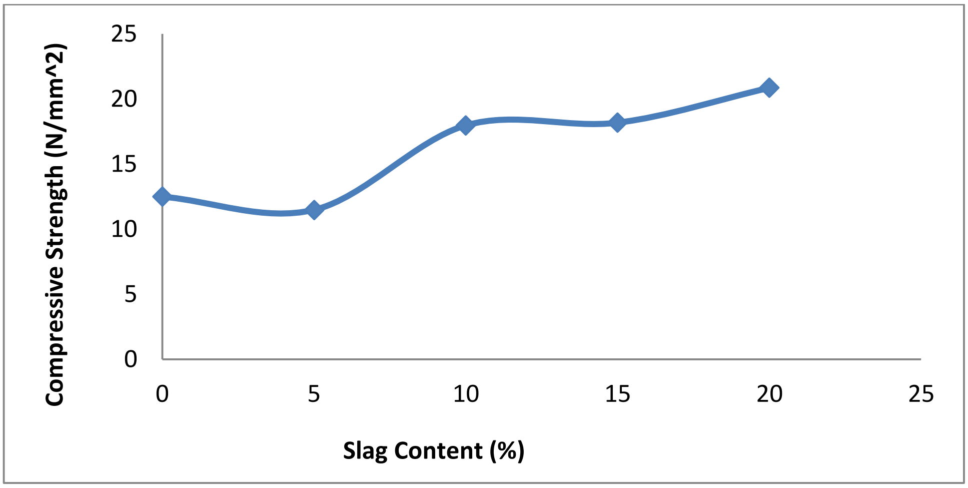

Fig. 3: Compressive Strength – Slag Content Characteristics for the Concrete Cubes at 28 days

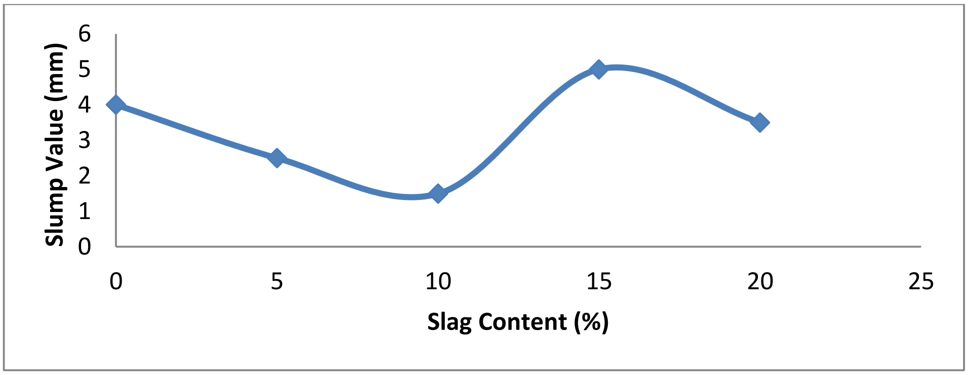

Fig. 4: Slump Value – Slag Content Characteristics for the Concrete Cubes

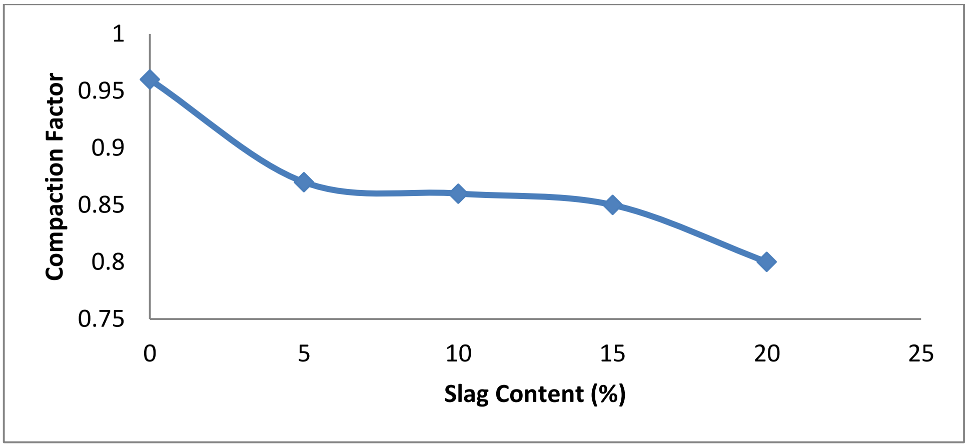

Fig. 5: Compaction Factor – Slag Content Characteristics for the Concrete Cubes

Chemical Composition

The microstructures and distribution of steel slag were studied with the aid of X-Ray Fluorescence spectrometer and X-Ray Diffractometer spectrometer that determined both chemical element and chemical composition. The oxides present in the steel slag (as evident from Table 2) include Aluminium oxide (Al_2O_3), Manganese oxide (Mn_5O_8), Iron oxide (Fe_2O_3), Silicon oxide (SiO_2) and other oxides.

Statistical Analysis (Analysis of Variance)

In order to determine whether there are significant differences between the compressive strength values of the concrete cubes, the compressive strength values of the cubes at 7, 14, 21 and 28 days (as shown in Table 1) for each proportion (0%, 5%, 10%, 15% and 20%) were employed for this purpose and Table 3 was prepared by subtracting an assumed mean of 13.2 from all the compressive strength values. Table 4 rounds off the computation of F value as the ratio of mean square between treatments to mean square within treatments.

Table 2: Elemental and Oxides Concentration in the Blast Furnace Slag

Element	Conc. (ppm)	Conc. Error	Oxides	Oxide (Conc.) %
Al	352.1	±46.20	Al_2O_3	0.0665
Si	9234.7	±350.92	SiO_2	1.976
S	1846.3	±181.49		
Cl	373.3	±90.49		
K	159.1	±30.05	K_2O	0.0192
Ca	261.1	±15.98	CaO	0.0365
Ti	160.5	±20.42	TiO_2	0.0267
Cr	571.0	±20.90		
Mn	1663.0	±40.91	MnO	0.215
Fe	316233.9	±347.86	Fe_2O_3	54.21
Zn	29.0	±9.26	ZnO	0.0036

Table 3: Analysis of Variance in Compressive Strength

	X_1-A	X_2-A	X_3-A	X_4-A	T_j	T_j^2
A (0% BFS)	-3.21	-2.53	-2.18	-0.70	-8.62	74.3044
B (5% BFS)	-5.61	-4.52	-3.54	-1.72	-15.39	236.8521
C (10% BFS)	-3.33	-0.49	0.34	4.78	1.24	1.5376
D (15% BFS)	-1.82	1.14	2.23	4.99	6.54	42.7716
E (20% BFS)	0.72	2.8	4.28	7.67	15.47	239.3209
		$\sum X_{jk}^2 = 243.6236$			-0.76	594.7866

Where X_1-A = compressive strength at 7 days minus the assumed mean,
X_2-A = compressive strength at 14 days minus the assumed mean
X_3-A = compressive strength at 21 days minus the assumed mean
X_4-A = compressive strength at 28 days minus the assumed mean

$\sum X_{jk}^2 = (-3.21)^2 + (-2.53)^2 + \ldots + 7.67^2 = 243.6236$

$V = \sum X_{jk}^2 - \frac{T\text{^}2}{ab} = 243.5947$ (a=5, b=4)

$V_B = \frac{1}{b}\sum T_j^2 - \frac{T\text{^}2}{ab} = 148.6678$

$V_W = V - V_B = 94.9269$

Table 4: Analysis of Variance in Compressive Strength (F Computation)

Variation	**Degrees** of Freedom	Mean Square	F

Between Treatments $V_B = 148.6678$	a-1=4	$S_B^2 = \frac{148.6678}{4} = 37.1670$	$F = \frac{37.1670}{6.3285} = 5.873$
Within Treatments $V_W = 94.9269$	a(b-1)=15	$S_W^2 = \frac{94.9269}{15} = 6.3285$	
Total V = 243.5947	ab-1=19		

$F_{0.95}=3.06$ and $F_{0.99}=4.89$

Since the values of F at 5% and 1% confidence levels are less than the computed value, the null hypothesis is hereby rejected that is, there are significant differences between the compressive strength values. The statistical model proves further that blast furnace slag could partially replace cement in the production of concrete.

4. Conclusion

The following conclusions can be drawn on the basis of the results obtained from the investigation of the use of Blast Furnace Slag (BFS) as a partial replacement for cement in concrete. The concrete cubes with 20% proportion of replacement (by slag) have the highest compressive strength value of 20N/mm^2. The slump value started increasing at 10% slag content with increasing proportion of BFS. In addition, the compaction factor was decreasing with increasing proportion of BFS. This signifies a low concrete workability for the slag–blended concrete at the chosen water-cement ratio. The partial replacement of cement with Blast Furnace Slag in concrete increases the compressive strength of the concrete significantly. Based on the tests carried out, it is hereby recommended that 20% of BFS should be used in concrete to increase the compressive and flexural strength and the curing age can be increased to determine if the steel slag will be dormant in the foreseeable future. This will show the effect of BFS on concrete for longer curing days.

Acknowledgements

The authors are indeed grateful to Technical Staff at Building Technology Department and Civil Engineering Students, Federal Polytechnic Ede, Nigeria for their assistance during the laboratory works.

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