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Investigation on the Potentials of Cupola Furnace Slag in Concrete

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Abstract: The compressive strength of the concrete designed using blast cupola furnace slag and granulated cupola slag as a coarse aggregate and partial replacement for cement was investigated. A series of experimental studies were conducted involve concrete production in two stages. The first stage comprised of normal aggregate concrete (NAC) produced with normal aggregates and 100% ordinary Portland cement (OPC). Meanwhile, the second stage involved production of concrete comprising of cupola furnace slag an aggregates with 100% ordinary Portland cement (OPC) and subsequently with 2%, 4%, 6%, 8% and 10% cementitious replacement with granulated cupola furnace slag that had been grounded and milled to less than 75 µm diameter. The outcomes of compressive strength test conducted on the slag aggregate concrete (SAC) with and without granulated slag cementitious replacement were satisfactory compared to normal aggregate concretes (NAC).

Keywords: Cupola furnace slag, compressive strength, normal aggregate concretes, slag aggregate concrete

1. Introduction

The dominant role of pure Portland cement is slowly decreasing in favour of substituted and composite cements. A very important development in our modern times is the steadily growing amount of substitutes such as industrial by-products, wastes, and unprocessed materials. These substitutes can be employed in the production of cements and concrete which make it possible to optimize the concrete durability in service [1-3]. The understanding and the use of metallurgical slag which constitute a majority of wastes from metallurgical processes is one of the promising developments. The use of industrial by-products features not only as a partial solution to environmental and ecological problems, but it also significantly improves the microstructure and consequently the durability properties of concrete, which has been found difficult to achieve by the use of pure Portland cement [4]. It has been verified that the substituted of blended cements or the cements based entirely on waste products, can provide performance properties that are better than or not found in Portland cement.

Slag generally possesses a unique glassy character, the structure and reactivity of which is very strongly dependent upon the chemical composition and cooling conditions. It is therefore, important that a greater understanding of the functionality of the material be understood before full commercialization [5].

Although many studies have been conducted on the evaluation of properties blast furnace slag, and other slag varieties to be used in civil engineering works, there are rare researches regarding the utilization of cupola furnace slag in concrete. ASTM C33[6] has provided a specification for the use of blast furnace slag as aggregates in concrete, however, there is no such a standard for cupola furnace slag use in concrete [7-8]. In this regard, this study evaluates the possibility of employing cupola slag as partial replacement of cement and as aggregates in concrete.

2. Material

2.1 Fine aggregate

Sand excavated from the river bed served as fine aggregate for all the concrete cube specimens. The river sand was sieved in-situ through 10 mm sieve to remove stubs, sticks and other forms of impurities that cause concrete properties to be compromised.

2.2 Coarse aggregate

Crushed rock of less than 20 mm diameter sizes was obtained from the quarry. The crushed rock was devoid of unwanted materials such as debris, clay and was used as aggregates in the control mixture.

2.3 Cupola furnace slag

The blast cupola furnace slag was obtained from the St. Daniel foundry dump site, araromi-Akure, Nigeria, in a large form. The slag was transported to the Metallurgical and Materials Laboratory, Federal University of Technology, Akure, Nigeria, where the total volume was split into two parts. The first part was crushed using Jaw crusher and a Pulverizer to sizes of less than 20 mm diameter in accordance with the mix design. The crushed slag need to be passed through 19 mm diameter sieve before being used as coarse aggregates. The second part was first dusted and isolated to remove visible earth impurities. It was then pulverized to less than 4 mm diameter sizes and was afterward ball

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milled to achieve the powdered granulated form of the slag. A final process of sieving through 75 µm sieve was carried out before it can be used as partial replacement for cement in the production of concrete.

2.4 Properties of materials

The properties of the fine, crushed rock aggregate and Cupola furnace slag are as presented in Table 1. It can be clearly understand from the fineness modulus, specific gravity and bulk density that the materials exhibit good qualities as recommended by BS812: Part101 (1985).

Table 1 Summary of materials properties.

	River Sand	Crushed Rock	Cupola Slag
Fineness Modulus	2.00	5.78	-
Specific Gravity, G_s	2.64	2.72	2.87
Bulk Density (kg/m^3)	1530	1530	1510

3. Method and Experimental Study

The revised edition of the normal concrete mixes manual published by British Department of the Environment and developed by the Building Research Establishment, Transport and Road Research Laboratory and the British Cement Association was used for the Concrete mix design. Five experimental stages of concrete production were embarked upon the production of concrete. Nine concrete cube specimens, each of 3.375×10^{-3} m^3 volume were produced with water-cement of 0.54 and a mix design ratio of 1: 1.49: 3.56. The river sand sample used as fine aggregate in concrete was oven-dried for 24 hours before further tests such as particle size distribution were carried out. The sand, crushed rock and cupola furnace slag were also used as aggregates. These materials were graded using the sieve sizes for grading according to BS812: part 103 (1985) [9]. Hence, the percentage passing through each set of sieves was determined.

The concrete ingredients were then mixed using the method of batching by weight in accordance with the provision of BS 812: Part 104 (1985) [10]. River sand having maximum particle size of 2.36 mm, determined from particle size distribution method, was first measured, and spread with shovel, after which ordinary Portland cement (OPC) was added and thoroughly mixed. The resulting mix was then mixed with coarse aggregate (granite) of maximum particle less than 20 mm diameter and the required amount of water. The resulting concrete was poured in the standard concrete cube mould of 150 x 150 x 150 mm in three layers. Each layer was given 25 blows for compaction using British Standard rod as recommended by BS1881: Part 111 (1983) [11]. The fresh concrete was tested in accordance with British Standards (1881: Part 102 (1983) [12] for slump. The concrete cubes were removed after 24 hours from the moulds, weighed and kept under water for curing in the curing tank. After every 7 days, three specimes of concrete cube were removed from the curing tank, weighed and tested for compressive strength. The values of compressive strength were read and recorded. The same procedure was followed for other concrete mix ratios using crushed copula furnace slag of less than 20 mm diameter as coarse aggregate. Also, by replacing ordinary Portland cement (OPC) with 2%, 4%, 6%, 8% and 10% of granulated (powdered pulverized) copula furnace slag cement.

4. Results and Discussion

4.1 Fresh concrete properties

The fresh concrete properties in term of slump value and concrete density according the percentage of copula furnace slag replacement can be seen in Table 2. It can be inferred that the consistency of the concrete measured by slump values and the density of the concrete for the tested concrete mix ratio are in compliance with the recommendation given by BS812: Part101 (1985) [13].

Table 2 Fresh concrete properties.

Slag Replacement (%)	Fresh Concrete Properties	
	Slump values (mm)	Concrete Density (kg/m^3)
0	67	2579.26
2	65	2555.56
4	63	2562.59
6	65	2568.10
8	66	2462.22
10	67	2577.80

4.2 Compressive strength

The outcome of experimental tests on the normal aggregate concrete (NAC) and the cupola slag aggregate (SAC) show satisfactory development and consistency in compressive strength of concrete as the age increased. The control concrete made with normal aggregates of crushed rock and river sand, though cured under same conditions as the copula furnace slag aggregate concrete, exhibited highest individual cube strength of 32.22 N/mm^2 as well as highest average strength of 31.33 N/mm^2, both occurred at 28 days of curing age as can be seen in Fig. 1.

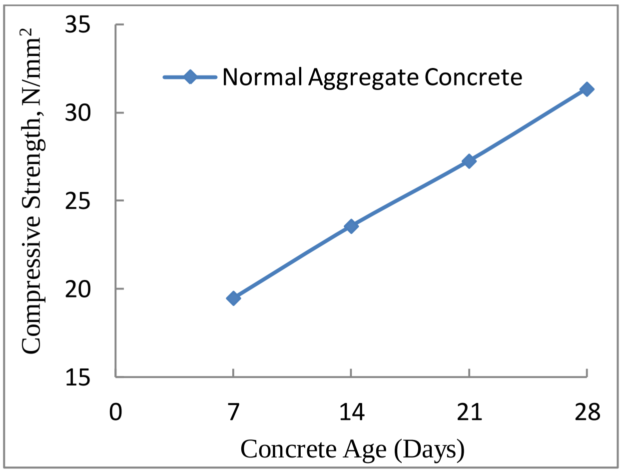

Fig. 1 Compressive strength for normal aggregate concrete (NAC) with 100% ordinary Portland cement.

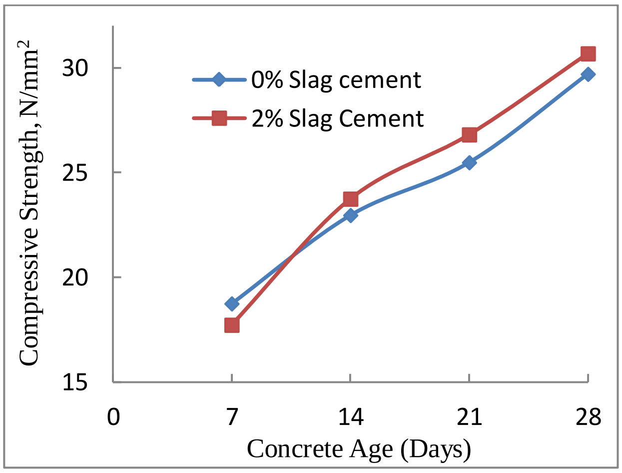

Fig 2 Compressive strength for slag aggregate concrete (SAC) with 2% slag cementitious replacement.

However, subsequent average compressive strength obtain were close; those of copula furnace slag aggregate concrete (SAC) with 2%, 4%, 6%, 8% and 10% cement substitution have compressive strength of 30.68 N/mm^2, 30.08 N/mm^2, 29.96 N/mm^2, 29.84 N/mm^2 and 29.78 N/mm^2, all attaining the 30 N/mm^2 specified design strength. Fig. 2 to Fig. 6 show the results of compressive strength for slag aggregate concrete with 2%, 4%, 6 %, 8% and 10% respectively, and comparison with slag aggregate concrete containing 0% of slag cementitious replacement.

Concretes made with granulated cupola slag cement substitutes show a trend, though not sizeable, in compressive strength. Taking the strength at 28 days of SAC without cement replacement as reference, SAC with 6%, 8% and 10% cement substitution showed a 0.13%, 0.53% and 0.73% reduction of 0.04 N/mm^2, 0.16 N/mm^2 and 0.22 N/mm^2 over the reference, while 2% cement substitution showed a 2.27% rise of 0.68 N/mm^2 and the 4% cement substitution attained a 0.27% rise of 0.08 N/mm^2.

The 28 days of compressive strengths of SAC with cementitious replacements rose compared to SAC without replacement, and showed a downward trend of strength as the percentage of cement substitution increased when compared amongst themselves. This gives the indication that higher percentage replacement of cement greater than 10% may yield a loss in concrete compressive strength. Despite the fact that SAC with 100% OPC and SAC with 10% cement substitution show least strengths, the compressive strength come off a 29.70 N/mm^2 and 29.78 N/mm^2 respectively. This can be justified as variations that resulted due to non-standard compaction conditions. The values obtained were such that they can be conveniently approximated, thereby still attaining the 30.00 N/mm^2 specified design 28 days strength.

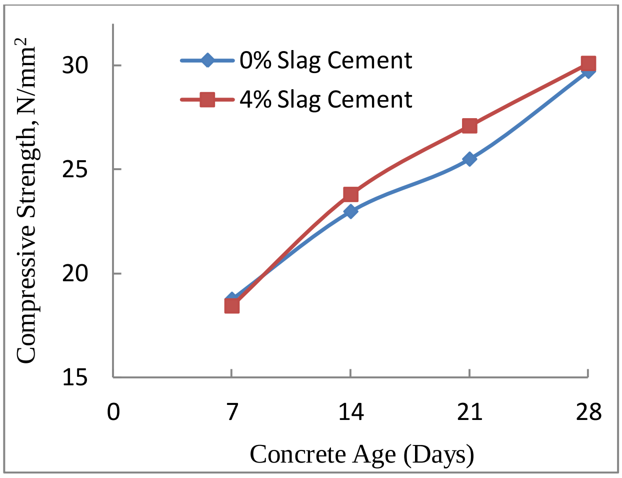

Fig. 3 Compressive strength for slag aggregate concrete (SAC) with 4% slag cementitious replacement.

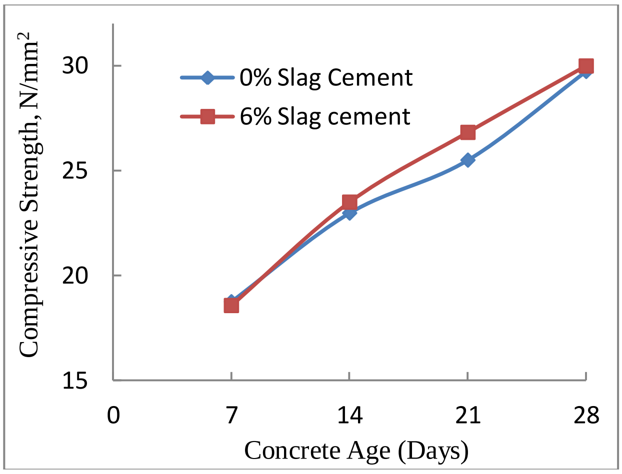

Fig. 4 Compressive Strength for slag aggregate concrete (SAC) with 6% slag cementitious replacement.

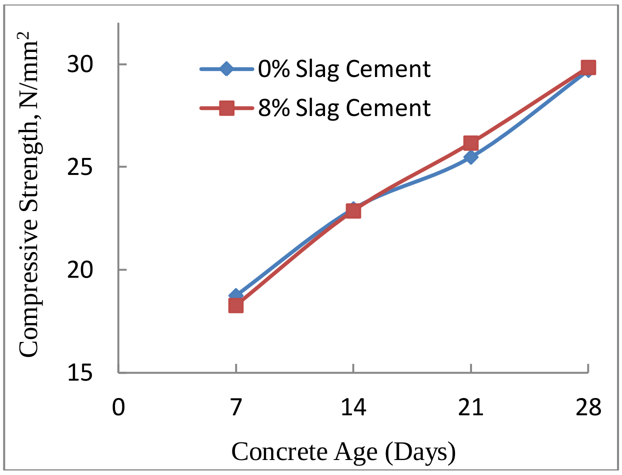

Fig. 5 Compressive strength for slag aggregate concrete (SAC) with 8% slag cementitious replacement.

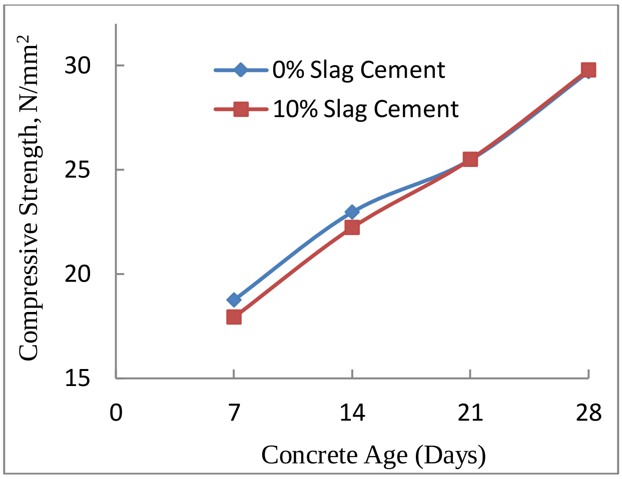

Fig.6: Compressive strength for slag aggregate concrete (SAC) with 10% slag cementitious replacement.

5. Summary

The results of compressive strength of the concrete designed using blast cupola furnace slag and granulated cupola slag as a coarse aggregate and partial replacement for cement has been presented. The outcomes of compressive strength test conducted on the slag aggregate concrete (SAC) were satisfactory compared to normal aggregate concretes (NAC).

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