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Utilization of Blast Furnace Slag as Coarse Aggregate in Concrete Production

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ABSTRACT

The presents high cost of construction materials in the country calls for alternatives which will also be appropriate for construction works and as well achieved the desired strength. The study reports on experimental investigation on the utilization of blast furnace slag (BFS) as full replacement for crushed granite in concrete production. Two control mixing ratios of 1 : 1½ : 3 and 1 : 2 : 4 batched by weight with water – cement ratio of 0.55 were used. The slump test was used to assess the workability of the fresh concrete. The compressive strengths and densities of cured concrete cubes of sizes 150mm x 150mm x 150mm were evaluated at 7days, 14days, 21days and 28days. A total of forty – eight (48) concrete cubes were cast and tested. The full replacement of crushed granite with blast furnace slag lowered the workability and density of the concrete cubes. The values of the density obtained were still within the normal concrete range. The compressive strengths and densities of both mixing ratio increase with days of curing. The compressive strength and density are maximum for concrete cubes with 100% crushed granite and minimum when blast furnace slag is 100%. Compressive strength results test showed that blast furnace slag has the potential to replace crushed granite and could be used for both structural and non - structural works. The use of BFS in concrete is an effective way of reducing the cost of concrete production since the BFS is a waste and has no cost value.

KEYWORDS: *blast furnace slag (BFS), concrete, ordinary Portland cement, coarse aggregate, compressive strength,*

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I. INTRODUCTION

Concrete is the most extensively used construction material in the world, and its acceptance can be accredited to two aspects. First, concrete is used for many different structures, such as dams,airport runways, tunnels, pavements, highways, high – speed railways, building frames, or bridges, much more than any other construction material. Second, the quantity of concrete used in the world is much more than any other material. Its worldwide production exceeds that of steel by a factor of 10 in tonnage and by more than a factor of 30 in volume. As of now, the annual world consumption of concrete has reached a value such that if concrete were eatable, every person on earth would have a total of 2000 kg per year to “eat” [22].

Concrete is produced by mixing cementing material, aggregates and water, and occasionally admixtures, in required proportions. The mixture when placed in forms and allowed to cure hardens into a rock – like mass known as concrete. Aggregates constitute a skeleton of concrete. Approximately 75% of the volume of conventional concrete is occupied by aggregate. It is unavoidable that a constituent occupying such a large percentage of the mass should contribute significant properties to both the fresh and hardened state [22].Aggregate is generally regarded as an inert, cheap material dispersed all over the cement paste in order to produce a large volume of concrete. However, firmly speaking, aggregate is not truly inert because thermal, physical and, occasionally, chemical properties can influence the concrete performance [17]. According to sizes, aggregates are divided into two namely coarse aggregate and fine aggregate. Coarse aggregates are the aggregate that predominately retained on No. 4 (4.75 mm) sieve and its sizes ranges from 5 to 150 mm. Fine aggregates are the aggregate that passing through a No. 4 (4.5 mm) sieve and predominately retained on a No. 200 (75 µm) sieve.

The choice of aggregate is determined by the proposed use and importance of structure, environmental conditions to which the structure will be exposed and the availability of aggregate within an economical distance. Aggregates in concrete serve three main functions: they provide a relatively cheap filler by rigid interlocking with cementitious binders; they serve to provide a cohesive mass of solids that resists the action of applied loads, percolation of moisture, the action of weather, and abrasion and erosion and, they reduce the volume changes resulting from the setting and hardening process from moisture changes in the cementitious paste thus reducing the cracking possibility of concrete.

Due to liberalization, globalization and privatization, the construction of important infrastructure projects like, buildings, roads, airports etc in Nigeria is increasing year after year. Such developmental activities consume large quantity of precious natural resources. This leads to faster depletion of natural resources on one side and manifold increase in the cost of construction of structures on the other side pose severe problem for the construction sector. This problem is very severe in Nigeria. In view of this, people have started searching for suitable other viable alternative materials which could be used either as a substitute or as a partial replacement to the conventional ingredients of concrete so that the existing natural resources could be saved to the possible extent and could be made available for the future generation.

In this process, the use of natural agricultural and industrial waste products has now become necessary as replacements to the use of granite that causes noise pollution during production according to Falade et al. [10]. The use of agricultural and industrial wastes to complement existing natural resources in construction provides both practical and economic advantages. The wastes usually have no commercial value and being locally obtainable, transportation cost is minimal [9]. Agricultural and industrial wastes have advantages over conventional materials in low cost construction [1]. According to Abutaha et al. [2],utilizing waste material in the construction industry is an effective way to protect the environment and minimize construction cost.

Numerous industrial waste products such as clay tile chips, ceramic tile, ceramic waste,steel furnace slag, steel making slag, broken tiles etc., and some of the agricultural by products like palm kernel shell, palm oil clinker, coconut shell, etc have been found useful as partial or fully replacement for coarse aggregate in the production of concrete. Aswathy et al. [6] carried out researched on the use of clay tile chips as coarse aggregate in concrete. They replaced the crushed natural stone aggregate in concrete with 25, 50, 75 and 100% clay tile chips using batching by volume. The results showed that replacement of natural aggregate by 25% by volume with the broken clay tile can be recommended without adjusting the mix design procedure. Sekar [20] investigated the influence of partial replacement of coarse aggregate with ceramic tile waste in concrete. The replacement percentage of 0, 15, 30 and 45% were used. The results showed that there is a significant increase in strength up to 15% replacement and beyond which there is no such improvement in the strength. It was found in the work of Ikponmwosa and Ehikhuenmen [13]that ceramic waste could be used for both structural and non - structural works and more than 75% replacement level of ceramic waste material should not be used in concrete structures where strength is the main consideration.

Zarina et al. [21] carried out research on the feasibility of palm kernel shell (PKS) as a replacement for coarse aggregate in lightweight concrete. They replaced the coarse aggregate in concrete with 0%, 25%, 50%, 75% and 100% PKS using Department of Environment (DOE) method of mix design. The results indicated that by using PKS for aggregate replacement, it increases the water absorption but decreases the concrete workability and strength. However, results fall into the range acceptable for lightweight aggregates and hence concluded that there is potential to use PKS as aggregate replacement for lightweight concrete. Abutaha et al. [2] investigated the effect of palm oil clinker (POC) aggregates on fresh and hardened properties of concrete. They replaced the total volume of fine and coarse aggregates with 0, 10, 20, 40, 60, 80 and 100% POC using Department of Environment (DOE) method of mix design to produce concrete of Grade 40. The results showed that the density of concrete was within the range of 2074 – 2358 kg/m^3 and POC displayed good ultrasonic pulse value (UPV) and an acceptable compressive strength of 33 – 49 MPa at 28 days. Therefore, POC has a good potential to replace natural aggregates, making it suitable to be used in concrete.

Alexander and Jeffery [5] studied steel furnace slag (SFS) aggregate expansion and hardened concrete properties. They developed a process to screen SFS aggregates for free oxide contents and expansion potential using thermogravimetric analysis, complexometric titration and an autoclave expansion test. They concluded that SFS aggregates in concrete can produce suitable strength properties, appropriate freeze/thaw durability, and excellent fracture properties. Though, the SFS aggregates produced better free drying shrinkage than concrete with dolomite aggregates. For SFS aggregates having low expansion potential, the hardened property tests show that SFS may be good to be used as aggregate for concrete. Jose et al. [14]conducted research on the performance of steel - making slag concretes in the hardened state. The results showed that overall concrete quality is achieved and that its performance is suitable for the proposed application. Mujedu et al. [16]investigated the suitability of broken tiles as coarse aggregates in concrete production. They concluded that the compressive strength and density are maximum for concrete cubes with 100% crushed granite and minimum when broken tiles content is 100%. The replacement of crushed granite with 39% to 57% broken tiles content showed satisfactory result.

Gunasekaran et al. [11]conducted a study on reinforced lightweight coconut shell concrete beam behavior under flexure. They produced twelve concrete beams out of which six were produced with coconut shell and remaining six were produced with normal control concrete. The results showed that the flexural behavior of coconut shell concrete is similar to that of other lightweight concretes. They concluded that concrete steel tension strain and compression strain results showed that coconut shell concrete is capable to attain its full strain capacity under effect of flexural loadings. Under the condition of serviceability, cracking and deflection characteristics of coconut shell concrete are similar with control concrete. Though, the failure zones of coconut shell concrete were higher than that of control concrete beams. They also concluded that the rotations at the end of the coconut shell concrete beams just before failure values are similar to other lightweight concretes. Osei and Jackson [19] reported that there exists a high potential for the use of palm kernel shells as aggregates in theproduction of lightly reinforced concrete. Palm kernel shell concrete batched by volume performed better than that batched by weight and replacement of 13% crushed granite by palm kernel shells in weight - batched concrete can be used in reinforced concrete construction while replacement of 8% if crushed granite in volume - batched concrete can be used in reinforced concrete construction.

Olanipekunet al. [18]carried out research on the comparative study of concrete properties using coconut shell and palm kernel shell as coarse aggregates. He replaced the coarse aggregate in concrete with 0%, 25%, 50%, 75% and 100% of either coconut shell or palm kernel shell using mix ratios of 1 : 1 : 2 and 1 : 2 : 4. He noted that the compressive strength of the concrete reduced as the percentage of the shells increased in the two mix ratios. Though, concrete produced from coconut shells showed a higher compressive strength than palm kernel shell concrete in the two mixing proportions. His results also showed a 42% and 30% cost reduction for concrete produced from palm kernel shells and coconut shells respectively. He concluded that coconut shells were more suitable than palm kernel shells when used as replacement for conventional aggregates in the production of concrete.

Information concerning studies on concrete made with different wastes is available in different forms in a scattered manner, and has also not sufficiently reached the large volume of stakeholders involved in the construction activities across the length and breadth of our country. Due to this, the effective utilization of potential industrial waste materials in concrete has not attained the expected level in Nigeria even today. Hence, there is a compulsion on the part of Civil Engineering community, to take appropriate strategies so that the consumption of such potential waste by the construction industries will be on rise day – by – day leading to a green environment which is of course the need of the hour for our nation.

As part of efforts to make efficient use of industrial wastes obtainable materials, this study was carried out to investigate the influences of fully replacement of conventional coarse aggregates with blast furnace slag on the workability, density and compressive strength of concrete as well as to assess the performance of blast furnace slag concrete as a structural material. Blast furnace slag is a byproduct acquired in the production of pig iron in the blast furnace and is involving essentially of silicates and alumino - silicates of calcium and of other bases, which is developed in an igneous condition consecutively with iron in a blast furnace [4].

II. EXPERIMENTAL PROCEDURE

2.1 Concrete Materials

Crushed granite used for the study was of size 19 mm. It was obtained from Ayofe quarry in Iwoye near Ede of Osun State of Nigeria. The blast furnace slag used was obtained at Prism Steel Mill, Ikirun in Osun State of Nigeria. It was packed in plastic sheets to prevent contact with water. Natural river sand used was obtained from Osun river while Elephant brand of ordinary Portland cement produced at the cement factory located at Sagamu in Ogun State of Nigeria as obtained from the open market at Ede in Osun State was used in the concrete production. Water supplied by Osun State Water Corporation in Ede was used in mixing the materials. The water looked clean and was free from any visible impurities. It conformed to the requirements of BS 3148 [8].

2.2 Mixing Proportions and Production of Concrete Cubes

The study utilized two control mixing ratio of 1 : 1½ : 3 and 1 : 2 : 4. Batching operation by weight approach was adopted in the study. Table 1 showed the batching information for concrete cube cast. A water – cement ratio of 0.55 was used in both mixing ratios. The casting was done in cube steel moulds measuring 150 mm x 150 mm x 150 mm internally. The cube steel moulds were assembled prior to mixing and properly lubricated with used engine oil for easy removal of hardened concrete cubes. The mixing was done on a dry, clean and hard surface free of all harmful materials which could affect the properties of the mix. The required quantity of sand was measured and spread using a shovel to a reasonably large surface area. The quantity of cement was measured and added to the already measured sand and the mixing continues until the whole mass becomes uniform in colour. Thereafter, a depression was made in the middle of the whole mass while the required quantity of granite was measured and spread evenly on it. The required quantity of water was then added gradually and turned over with shovel until the mix appeared in colour and consistency. This was repeated again by replacing the granite with blast furnace slag to produce another batch of concrete. All together, the concrete cubes were prepared with four batches.

The already cleaned cube moulds were then filled with prepared fresh concrete in three layers and each layer was compacted with tamping rod using twenty five strokes uniformly distributed across the seldom of the concrete in the mould. The top concrete was later smoothened by hand – trowel to level with the edge of the mould and then left in the open air for 24 hours. The concrete cubes were made in accordance with BS 1881 [7]. For each batches of concrete produced, twelve cubes of concrete were cast and therefore, a total of forty – eight (48) cubes were produced for testing. The concrete cubes were demoulded after 24 hours of the concrete hardened under air. They were then immersed into a large curing tank measuring 3.0m x 1.5m in order to increase the strength of the concrete, promote hydration, eliminate shrinkage and absorb heat of hydration until the day of test. Concrete cubes prepared were cured for 3, 7, 14, 21 and 28 days. The concrete cubes were weighed before testing and the densities of cubes at different time of testing were measured. Before the testing, the concrete cubes were removed from the curing tank and left in the open air for about two (2) hours before crushing.

The compressive strengths of the concrete cubes were tested in accordance to BS 1881 [7] using Digital compression machine which automatically evaluates the compression load and displays the results on an LCD screen. In all, 48 numbers of concrete cubes were tested.

III. TESTING

3.1 Slump Test

The slump test measures the consistency of the concrete, and considered as the standard test for the workability of concrete according to BS 1881 [7].

3.2 Density

Before the compressive strength test was carried out, the mass of the concrete cube specimens were taken to determine the density of the concrete cubes. The density of the concrete cubes were later obtained from the mass and volume of the concrete cube which is calculated as :

$$Density \quad = \quad \frac{M}{V} \quad ----------- \quad (i)$$

Where :

M = Mass of the Concrete Cube and V = Volume of the Concrete Cube

3.3 Compressive Strength Test

Before crushing, the cubes were brought out of the storage curing tank and kept for about 60 minutes for most of the water to wipe off. They were later weighed on a weighing balance and then taken to the digital compression machine with maximum capacity of 1000kN in accordance with BS 1881 [7]. The load on the cube was applied at a constant rate of stress equal to 0.01N/mm^2 per second. The concrete cubes experienced cracks due to failure in their strength as a result of the load applied by the compression machine. The compressive strength was recorded to the nearest 0.01N/mm^{2}and the value was the average of three concrete cubes.

IV. TEST RESULTS AND DISCUSSIONS

4.1 Workability

The workability of concrete batches for concrete cubes using slump test is shown in Table 2. It can be seen from the Table 2 that for both mixing ratio used, the workability of concrete decreases irrespective of the types of coarse aggregate used. The workability of concrete when using granite as coarse aggregate is higher than the workability of concrete when the coarse aggregate is fully replaced with blast furnace slag. The reduction in workability is attributed to the fact that blast furnace slag has more angular shapes than granite and it is lighter than granite, thus requiring more water to make the concrete workable.

4.2 Density

The relationship of the density with days of curingforconcrete produced with granite and blast furnace slagfor mixing ratiosof 1 : 1½ : 3 and 1 : 2 : 4 are expressed graphically in Figures 1 and 2. From the result, it can be revealed that the density increased with the days of curing. The concrete produced with granite has the highest density values irrespective of the days of curing than the concrete produced with blast furnace slag. The decrease in density was due to blast furnace slag being lighter and more porous than the granite. The results also revealed that for the same days of curing, the concrete produced with mixing ratio of 1 : 2 : 4 has the highest density values than the one produced with mixing ratio of 1 : 1½ : 3. This is predictable because the concrete produced with 1 : 2 :4 mixing ratio has much quantity of granite or blast furnace slag than the one produced with 1 : 1½ : 3 mixing ratio. This implies that the granite or blast furnace slag in 1 : 2 : 4 mixing ratio is densely packed and there are fewer voids to be filled by sand and cement as compared with the1 : 1½ : 3 mixing ratio. The values of all the densities for both mixing ratio irrespective of the types of materials used as coarse aggregate were in the density range for normal concrete of between 2200 – 2550 kg/m^3 in accordance with ACI 116R - 00 [3].However, using BFS as full replacement for coarse aggregate will cause a decrease in self – weight of concrete structural elements.

4.3 Compressive Strength

The variation of the compressive strength with days of curing for concrete produced with granite and blast furnace slag for mixing ratios of 1 : 1½ : 3 and 1 : 2 : 4 are expressed graphically in Figures 3 and 4. The figures show that compressive strength generally increases with days of curing. The values of compressive strength of concrete cubes produced with granite and BFS for mixing ratio 1 : 1½ : 3 at 7 days are 12.44 N/mm^2 and 11.11 N/mm^2 respectively while at 28 days, the values are 20.00 N/mm^2 and 18.96 N/mm^2 respectively. At 28 days, the compressive strength has increased by 61% and 71% for granite and BFS and this is an indication of the effect of days of curing on the strength development of concrete.The same trend occur for the mixing ratio 1 : 2 : 4, the values of compressive strength at 7 days were 10.07 N/mm^2 and 9.01 N/mm^2 respectively while at 28 days, the values were 17.93 N/mm^2 and 17.33 N/mm^2 respectively. At 28 days, the values were increased by 78% and 92% for granite and BFS. The concrete produced with granite has the highest compressive strength values irrespective of the days of curing than the concrete produced with BFS. The reduction in concrete compressive strength with BFS aggregates could be due to poor paste - aggregate bonding as a result of hydration or reaction products on the surface of the slag particle[5, 15].The decrease in concrete strength observed with BFS coarse aggregate may also be due to the high void present on the surface and inside the BFS aggregate, thereby making its load carrying capacity to be fairly low. Moreover, BFS is flaky and rough in nature unlike granite with a smother surface; this inconsistence shape might also affect the loading capacity and the interlocking bond between the aggregates[12]. The concrete produced with mixing ratio 1 : 1½ : 3 has the highest values of compressive strength irrespective of the days of curing than the concrete produced with mixing ratio 1 : 2 : 4. This is due to the fact that the concrete produced with 1 : 1½ : 3 mixing ratio has more quantity of cement than the one produced with 1 : 2 : 4 mixing ratio. As a thumb rule, the higher the quantity of cement in the concrete, the higher value will be the strength.Strength comes from inter - particle force transfer between sand grains and also from shear resistance provided by cement acting as adhesive. If the volume of the concrete remains the same and the proportion of cement in relation to that of sand is increased, the surface area of the concrete will increase. When the surface area of the concrete has increased, the water demand will stay the same for the constant workability. If the cement content in the concrete increase for no increase in water demand, the water - cement ratio will reduce and if the water - cement ratio reduces, the strength of the concrete will increase.

V. COST IMPLICATIONS

The results in Figures 3 and 4 have indicated that it is possible to make use of blast furnace slag to substitute crushed granite in the production of concrete. Since blast furnace slags are acquired at virtually no cost and the money to be used to procure granite in weight - batched concrete can be saved. Consequently, cost of producing concrete would be reduced as granite is fully replaced by blast furnace slags.

VI. TABLES AND FIGURES

Table 1: Batching Information for Concrete Cubes Cast

Mixing Ratio of 1 : 1½ : 3			
Cement (kg)	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	
	Sand	**Granite**	**Blast Furnace Slag**
17.67	26.51	53.02	0
17.67	26.51	0	53.02
Mixing Ratio of 1 : 2 : 4			
Cement (kg)	**Fine Aggregate (kg)**	**Coarse Aggregate (kg)**	
	Sand	**Granite**	**Blast Furnace Slag**
13.89	27.77	55.54	0
13.89	27.77	0	55.54

Table 2: Slump Value of Concrete Cubes

Concrete Type	**Concrete Mix Ratio**	**Slump Value (mm)**
Granite	1 : 1½ : 3	48
		47
	1 : 2 : 4	46
		45
Blast Furnace Slag	1 : 1½ : 3	43
		41
	1 : 2 : 4	40
		39

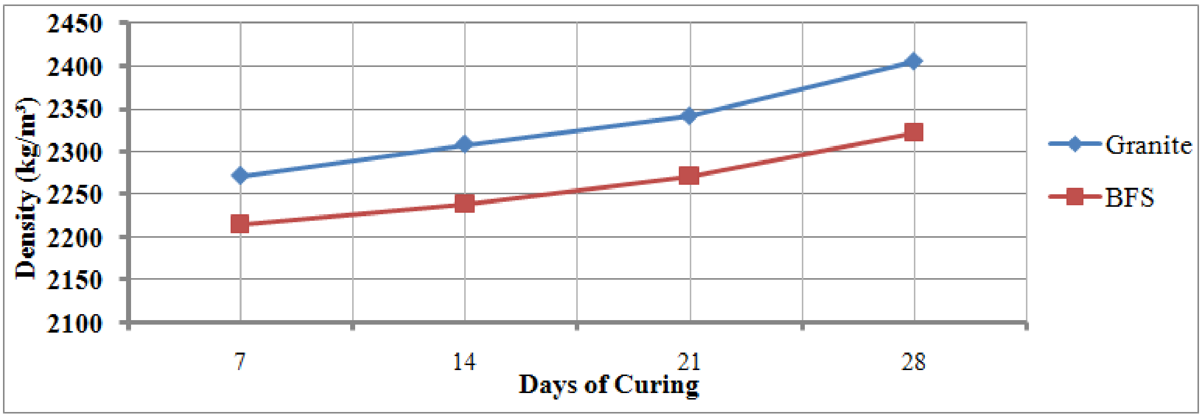

Figure 1: Variation of Density with Days of Curing for 1 : 1½ : 3 Mixing Ratio

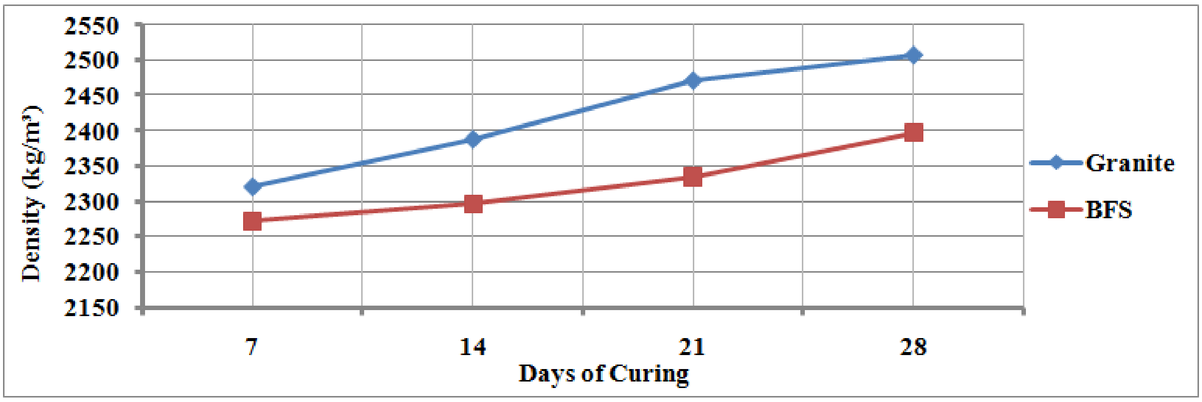

Figure 2: Variation of Density with Days of Curing for 1 : 2 : 4 Mixing Ratio

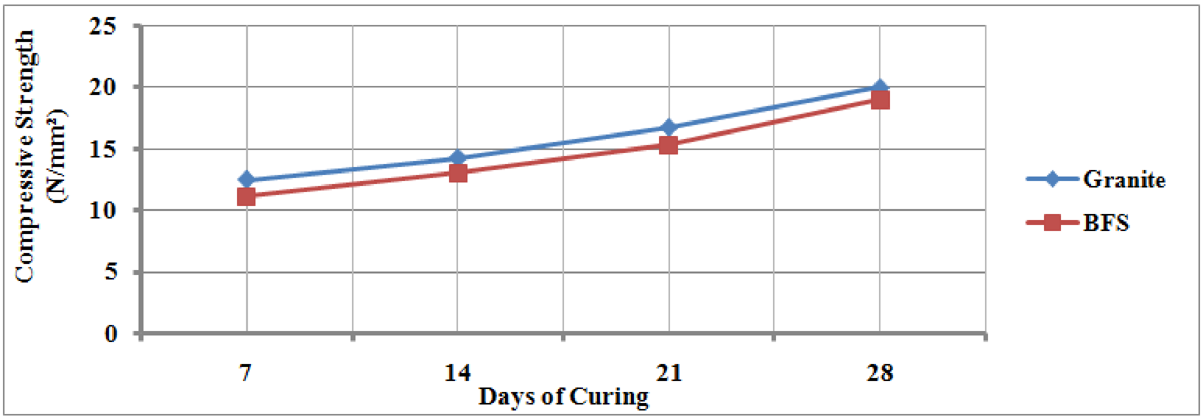

Figure 3: Variation of Compressive Strength of Concrete Cubes with Days of Curing for 1 : 1½ : 3 Mixing Ratio

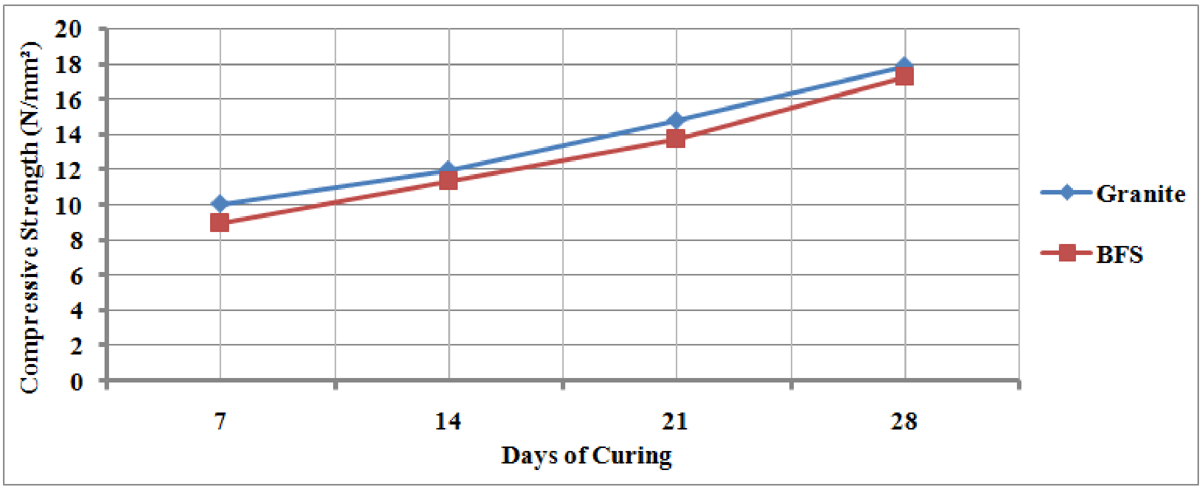

Figure 4: Variation of Compressive Strength of Concrete Cubes with Days of Curing for 1 : 2 : 4 Mixing Ratio

VII. CONCLUSION

Based on the experimental work and test results obtained, the following conclusions were derived:

1. The workability of concrete decreases irrespective of the types of coarse aggregate used. The value of workability is higher in granite than when BFS is used as coarse aggregate.
2. The use of BFS as full replacement for coarse aggregate in concrete production caused decrease in its density though the values were still within the normal concrete range. If used, this also could result in reduced self – weight of concrete structural elements.
3. The compressive strength of concrete cubes always increases with the days of curing. The concrete produced with granite has the highest compressive strength values than the concrete produced with BFS.
4. Compressive strength of the BFS concrete obtained at 28 days are 18.96 N/mm^2 and 17.33 N/mm^2 for 1 : 1½ : 3 and 1 : 2 : 4 respectively. This strength indicates that BFS has the potential to replace natural coarse aggregate and could be used for both structural and non – structural works.
5. The use of BFS in concrete is an effective way of reducing the cost of concrete production since the BFS is a waste and has no cost value.

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