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DENSITY, WORKABILITY AND COMPRESSIVE STRENGTH ASSESSMENT OF STEEL SLAG IN CONCRETE

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Abstract: This study examines the use of Steel Slag (SS) as a partial replacement of coarse aggregate in concrete. The replacement levels of crushed stone (granite) with SS were 0%, 10%, 20%, 30%, 40% and 50%. A total of 72 concrete cubes of sizes 150 mm x 150 mm x 150 mm were cast and cured in water for 7, 14, 21 and 28 days respectively. A mix ratio of 1:2:4 was adopted and batching was done by weight. Slump test were conducted on fresh concrete while density test and compressive strength test was conducted on hardened concrete. The compressive strength result shows that the strength of concrete increases with respect to curing age as the percentage of SS increases (i.e the higher the percentage of SS, the higher the compressive strengths of the concrete cubes). The replacement of coarse aggregate (crushed stone) with Steel Slag (SS) will produce a concrete of higher strength compared to plain concrete (conventional concrete). However, Steel Slag (SS) can successfully be used as a partial replacement of coarse aggregate (crushed stone) in concrete for concrete grade M20 since the strength of concrete with 10%, 20% and 30% 40% and 50% is higher than the control mix.
Keywords: Concrete, Coarse Aggregate, Compressive strength, Steel Slag (SS)

INTRODUCTION

Concrete has been the most common building material for many years. It is obtained by mixing cementitious materials, water, aggregate (usually sand and gravel or crushed stone) and sometimes admixtures in required proportions (Odeyemi et al., 2015). The aggregates typically account about 75% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability.

Conventional concrete consists of sand as fine aggregate and gravel, limestone or granite in various sizes and shapes as coarse aggregate. There is a growing interest in using waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitutes (Saravanan et al., 2015). Thus, waste materials such as coconut shell, palm kernel shell, blast furnace slag, and steel slag aggregate will address global warming and environmental problem.

Use of more and more environmental friendly materials in any Industry in general and construction industry in particular, is of paramount importance. Steel slag aggregates are already being used as aggregates in asphalt paving road mixes due to their mechanical strength, stiffness, porosity, wear resistance and water absorption capacity. Also, steel slag could be used as a partial replacement for coarse aggregate (Padmapriya et al., 2015). Therefore, there is need for the utilization of this by-product (steel slag) in concrete production in Nigeria as cost of natural aggregates (fine and coarse aggregate) is becoming higher.

Saravanan et al., (2015) evaluate the mechanical properties of concrete using steel slag aggregate. They concluded that 100% replacement of conventional aggregate with steel slag aggregate was not found to yield better strength.

However, the result of their study shows that: compressive strength of steel slag concrete increases in 6 % compared to the conventional coarse aggregate concrete; split tensile strength of steel slag concrete increases in 28 % compared to the conventional coarse aggregate concrete and flexural strength of steel slag concrete increases in 34 % compared to the conventional coarse aggregate concrete.

Sharma et al., (2015) examined the effects of steel slag on concrete. From their results, they observed that as the percentage of steel slag is increased (from 0% to 55%), the strength of concrete increases. After 55% replacement of coarse aggregate as steel slag, slight decrease in strength is observed, yet it is higher than 0% replacement without any adverse effect on the strength of concrete.

Ravikumar et al., (2015) investigated replacement of steel slag as coarse aggregate in concrete. In their study, concrete of grade M20, M30, M40 and M50 were considered for a W/C ratio of 0.55, 0.45, 0.37, 0.32 respectively for the replacement of coarse aggregate 30% 60% and 100% by steel slag.

The result of their finding revealed that there is an improvement in compressive strength from 5% to 10% for all the grades of concrete, 4 to 8% increase in split tensile strength in all grades of concrete and flexural strength of concrete increased between 2 to 6% for all the grades.They concluded that steel slag can be used up to 60% replacement in concrete grade M20, M30, M40 and M50 respectively while full replacement by steel slag decreases the strength considerably.

MATERIALS AND METHODS

- **Cement.** The cement used in the production of the concrete was Ordinary Portland cement (OPC) – Dangote cement brands 42.5R which conformed to NIS 444 – 1:2003.
- **Water.** Water is a universal solvent; it increases the workability of concrete mix. Water used for concrete mix in this study was obtained from tap.
- **Fine Aggregate.** The fine aggregate used in this research was natural sand most of which passes through sieve 4.75mm and conformed to IS 383-1970.
- **Coarse Aggregate.** Crushed stone (granite) of maximum size 19.0mm was used and conformed to IS 383-1970.
- **Steel Slag (SS).** Steel slag (SS) is a by-product obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. Steel slag is defined by the American Society for Testing and Materials (ASTM) as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminium, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open hearth furnaces (Sharma et.al. 2015).

The Steel Slag (SS) used for this research was collected from Machine Tools, along Osogbo – Ikirun Road, Osogbo, Osun State, Nigeria. The slag was crushed into smaller sizes manually and allow to pass through sieve size No 25mm and retained on sieve size No 19mm. Chemical composition of steel slag as reported by Ravikumar et. al. (2015) is shown in Table 1.

Table1: Typical value chemical composition of steel slag

Oxides	Composition (%)
Aluminium oxide (Al_2O_3)	1 – 3
Calcium oxide (CaO)	40 – 52
Iron oxide (FeO)	10 – 14
Magnesium oxide (MgO)	5 – 10
Manganese oxide (MnO)	5 – 8
Silica	30 – 35

Source: Ravikumar et al., (2015)

This study examines the use of Steel Slag (SS) as a partial replacement of coarse aggregate in concrete. The replacement levels of crushed stone (granite) with SS were 0%, 10%, 20%, 30%, 40% and 50%. A total of 72 concrete cubes of sizes 150mm x 150mm x 150mm were cast and cured in water for 7, 14, 21 and 28 days respectively.

A mix ratio of 1:2:4 was adopted and batching was done by weight with water-cement ratio of 0.45. At the end of the different curing ages, the densities of the cubes were determined and the cubes were crushed using a compression testing machine to determine their compressive strengths. Average values of concrete densities and compressive strengths for the various curing age and percentages of SS replacement with crushed stone (granite) were obtained and presented in Tables 3 and 4 respectively.

RESULTS AND DISCUSSION

Specific Gravity Test

The result obtained from specific gravity of fine and coarse aggregate are shown in Table 2.

Table 2: Specific gravity of Fine, Coarse Aggregate and Steel Slag

S/No.	Test Samples	Specific Gravity
1.	Fine Aggregate	2.53
2.	Coarse Aggregate	2.60
3.	Steel Slag	2.64

The range of specific gravity of aggregates as specified by ACI Education Bulletin E1 (2007) ranges from 2.30 to 2.90. The results of specific gravity of fine, coarse aggregate and steel slag (SS) shown in Table 2 are within the acceptable limits for aggregates.

Fineness Modulus

The fineness modulus was conducted in accordance with ACI Education Bulletin E1 (2007). From the sieve analysis, the following fineness modulus as shown in Table 3 was obtained.

Table 3: Fineness modulus of Fine, Coarse Aggregate and Steel Slag

S/No.	Test Samples	Fineness modulus
1.	Fine Aggregate	2.7
2.	Coarse Aggregate	5.2
3.	Steel Slag	6.1

ACI Education Bulletin E1 (2007) reports that fineness modulus is most commonly computed for fine aggregates, while the fineness modulus of coarse aggregate is needed for some proportioning methods. However, for fine aggregate used in concrete, the fineness modulus (FM) generally ranges from 2.3 to 3.1. The result of fineness modulus in Table 3 falls within the acceptable limits for fine aggregates.

Slump Test on Fresh Concrete

SS EN 206-1 (2009) describe slump test as test related with the ease with which concrete flows during placement. The three kinds of slump (as shown in Figure 1) describe by SS EN 206-1 (2009) are: natural or true slump (the concrete mould simply sinks, keeping its shape more or less), shear slump (the concrete mould falls away sideways) and collapse slump (the concrete mould collapses completely).

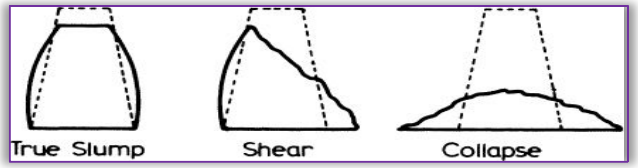

Figure 1: The three kinds of slump (Source: Neville, A.M., 2011)

The slump test was carried out in accordance with ASTM C192/C192M (2006). Table 4 shows the slump tests results for the concrete with varying replacement of SS.

Table 4: Results of Slump Test of concrete with Different Percentages of SS

Concrete properties	Percentage Replacement (%)					
	0	10	20	30	40	50
Slump (mm)	45	43	40	39	38	35

In this study, true slump was exhibited by the concrete in the fresh concrete mix. Table 4 shows that the slump height values reduce and the concrete becomes less workable (stiff) as the percentage replacement of coarse aggregate with steel slag increases. The result is represented in Figure 2.

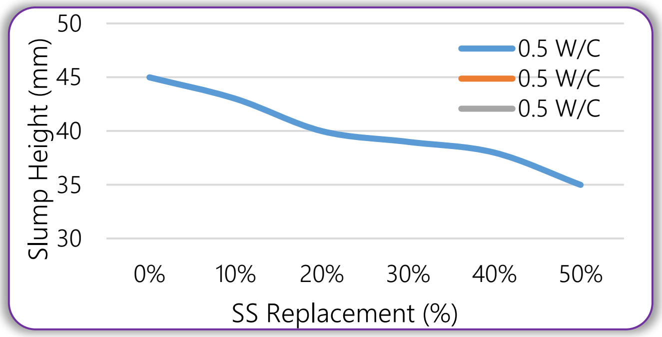

Figure 2: Slump height against SS replacement

Density Test on Hardened Concrete

The mean densities of concrete cubes made with different replacement level of SS for age 7, 14, 21 and 28 days curing (hydration period) respectively are given in Table 5. The density test conforms to BS EN 12390-7: 2009.

Table 5: Results of Mean Densities of Concrete Cube

Curing Age (Days)	Mean Densities of Concrete Cube (Kg/m^3)					
	0%	10%	20%	30%	40%	50%
7	2335	2340	2410	2400	2400	2350
14	2364	2337	2400	2407	2430	2390
21	2399	2453	2494	2446	2430	2400
28	2400	2443	2471	2480	2490	2420

All concrete cubes produced falls within the range of 2300Kg/m^3-2500Kg/m^3 and the densities of all the samples tested fell within the normal range of concrete as reported by Jones (1999). The result is presented in Figure 3.

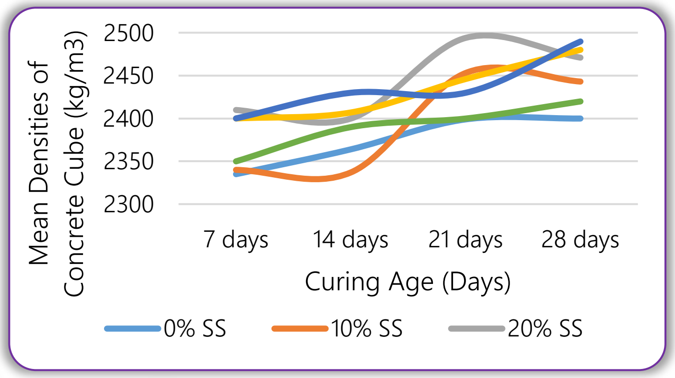

Figure 3: Relationship between concrete cubes mean densities and curing age

Compressive Strength Test on Hardened Concrete

The compressive strength tests on the SS concrete cubes were carried out with compression testing machine (2000kN capacity) at the soil mechanics laboratory, Civil Engineering Department, The Federal Polytechnic, Offa, Nigeria. This was done in accordance with BS EN 12390-3:2009 and CS1:2010. Tables 6 shows the compressive strength test results of the concrete cubes.

Table 6: Results of Mean Compressive Strengths

Curing Age (Days)	Mean of Compressive Strengths aggregate (N/mm^2)					
	0%	10%	20%	30%	40%	50%
7	12.11	14.20	15.48	17.04	17.55	15.50
14	17.39	17.88	19.00	19.75	20.00	17.90
21	20.63	21.22	21.99	22.86	22.90	20.55
28	23.55	25.40	26.55	26.79	26.95	23.70

The compressive strength results from Table 6 shows that the conventional mix (0%) is lesser than concrete with 10%, 20%, 30%, 40% and 50% replacement of crushed stone (granite) with SS.

However, the results show that the compressive strength of concrete increases with respect to curing age as the percentage of SS increases (i.e the higher the percentage of SS, the higher the compressive strengths of the concrete cubes).

At 7 days, the compressive strength results of 0% is lower than the minimum required compressive strength of 13.5 N/mm^2 for concrete grade 20 as specified by BS8110 Part 2:1985 (Table 7) while the strength of 10%, 20%, 30%, 40% and 50% of crushed stone with SS respectively met the minimum required compressive strength of 13.5 N/mm² for grade 20 concrete specified by BS8110 Part 2:1985 (Table 7).

Table 7: Required/Recommended Strength of Concrete (BS8110 Part 2, 1985)

Grade	Characteristic strength, f_{cu} (N/mm²)	Cube Strength at an age of:				
		7 days	2 months	3 months	6 months	1 year
20	20.0	13.5	22	23	24	25
25	25.0	16.5	27.5	29	30	31
30	30.0	20	33	35	36	37
40	40.0	28	44	45.5	47.5	50
50	50.0	36	54	55.5	57.5	60

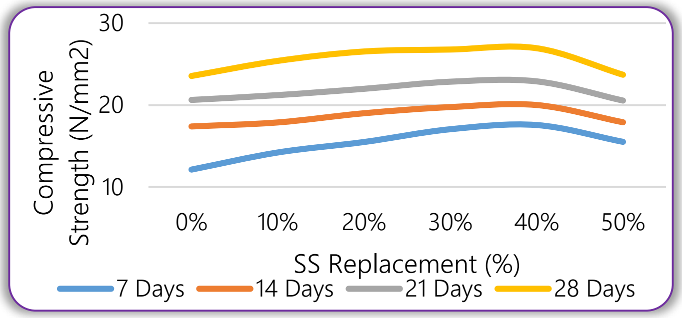

Figure 4: Graphical representation of compressive strength against SS Replacement

At 28 days, the strength of 0% was above the specified value of 20 N/mm²for grade 20 concrete (BS8110 Part 2:1985; Table 7) while the strength of 10%, 20%, 30% and 40% partial replacement of crushed stone with SS respectively was above the specified value of 20 N/mm²for grade 20 and 25 N/mm²for grade 25 concrete respectively (BS8110 Part 2:1985; Table 7).

Moreover, the compressive strength of concrete cubes increase with increase in steel slag from 0%SSto 40%SS but decreases at 50%SS. The results are represented in Figure 4.

CONCLUSIONS

From the experiment and results, the following conclusions can be drawn:

- True slump was exhibited by the concrete in the fresh concrete mix. However, the slump height reduces as the percentage replacement of coarse aggregate with steel slag increases.
- The compressive strength result of the conventional mix (0%) is less than concrete with SS. However, the compressive strength of concrete cubes increase with increase in steel slag from 0%SS to 40%SS but decreases at 50%SS. The compressive strengths result at 28 days shows that 40%SS have the highest compressive strength of26.95N/mm² followed 30%SS (26.79 N/mm²), 20%SS (26.55 N/mm²), 10%SS (25.40 N/mm²), 50%SS (23.70 N/mm²) and 0%SS (23.55 N/mm²).
- Further investigation should be carried out to determine the optimum addition of Nigerian Steel Slag (SS) as partial replacement for coarse aggregate in concrete.
- Steel Slag (SS) can successfully be used as a partial replacement of coarse aggregate (crushed stone) in concrete for concrete grade M20 and structural work.
- The replacement of coarse aggregate (crushed stone) with Steel Slag (SS) will produce a concrete of higher strength and better durability compared to plain concrete (conventional concrete).
- Nigerian government (federal and state) should lay emphasis on the use of steel slag in construction work for contractors in order to economize cost of coarse aggregate (crushed stone).

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