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СРЯЗВАНЕ ЧРЕЗ ТРИЕНЕ НА БЕТОН, СЪДЪРЖАЩ ШЛАКОВИ ДОБАВЪЧНИ МАТЕРИАЛИ КАТО ЕДЪР ДОБАВЪЧЕН МАТЕРИАЛ В УСИЛЕНИ БЕТОНИ

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SHEAR FRICTION OF CONCRETE CONTAINING STEEL SLAG AGGREGATE AS COARSE AGGREGATE IN REINFORCED CONCRETE

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Abstract:

Shear friction is the parameter which estimates the maximum shear force transmitted across a cracked plane in a concrete member. This research examines the influence of Steel Slag Aggregate (SSA) on the shear friction capacity of concrete. Steel slag was used to replace natural coarse aggregate at various percentage replacements of 0%, 25%, 50%, 75% and 100%, while two water-cement ratios of 0.55 and 0.65 were considered. Nine reinforced corbel specimens of sizes 125x250x550 mm were cast and tested for shear friction at ages 7, 14 and 28 days. Results show that slag concretes have good workability up to 50% replacement level but are generally less workable compared to normal concrete and its workability decreased as the percentage slag content increased in the concrete. Density of SSA concrete decreased as percentage replacement increased and at higher water-cement ratio. The density of 2492 kg/m^3 was recorded for slag concrete at 25% slag content and water-cement ratio of 0.55. The compressive strength and shear-friction capacity of slag concrete was found to decrease as the percentage slag content increased. The highest compressive strength recorded for slag concrete was 31.89 N/mm^2 (w/c = 0,65) at 25% slag content while the lowest was 20.44 N/mm^2 (w/c = 0,55) at 100% slag content. This shows that slag concrete can attain adequate strength for structural use.

Keywords:
Compressive Strength, Density, Shear-friction, Steel Slag Aggregates, Workability.

1. INTRODUCTION

Steel slag is a byproduct 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

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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, aluminum, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc, or open hearth furnaces. Approximately 96 to 145 million metric tons of steel slag are produced yearly (Akinwunmi et. al., 2012). Most often, steel slags are disposed around the steel producing centres thereby posing environmental threats. Not much research work has been reported on the use of steel slag produced from scrap metals in Nigeria.

Anastasiou et al. (2006), conducted several tests with slag aggregates in concrete and found out that the 28 day strength was increased by 21% with replacement of natural aggregates, while there was no increase in the setting time of concrete mixtures. Also they reported that the cement-aggregate interface seemed to be very dense without cracks or other discontinuities and concluded that the concrete that is produced with steel slag aggregates is of high specific gravity compared to conventional concrete.

Mahmoud et al. (2012), conducted a study on evaluation of the use of air cooled steel slag as a replacement for natural fine aggregate in concrete pavements. The steel slag from basic oxygen furnace was used for the study. They observed that the maximum compressive strength value was seen to occur at 25% fine aggregate replacement and the compressive strength goes on decreasing beyond this value. They also found that the flexural strength of steel slag concrete is greater when compared to conventional concrete for all their replacement ratios.

Salau et al. (2013), studied the use of steel slag as coarse aggregate in concrete. In their study, steel slag was used to replace granite between 0 and 100% at an interval of 20% for different mixes. Their results showed that the specific gravity, moisture content and water absorption of steel slag were found to be 2.41, 0.318 and 3.11 respectively. They reported that the workability of slag concrete decreased as the percentage replacement of natural coarse aggregate with slag increased. The compressive strength test on cubes showed that optimum strength was obtained at the 40% slag content. Their shear test results showed an increase in the shear strength of slag concrete beam as the percentage of steel reinforcement increases, just as in normal concrete. Also, they opined that shear capacity increases as the shear span/effective depth reduces, irrespective of the slag content and the percentage of steel reinforcement. They concluded that the deflections of slag concrete beams were higher than that of normal concrete and they exhibit higher ductility.

Paul et al. (2008), studied the use of steel slag in concrete. The slag was analyzed chemically and it did not show any presence of free lime or any other unstable substances, which can cause swelling effects. Four trial mixes were made with different water/cement ratio and compared with reference mix of crushed gravel as coarse aggregates. Their results showed an improvement in strength properties of steel slag aggregate concrete.

2. MATERIALS AND METHOD

2.1. Materials

All concrete mixes used were made from Ordinary Portland Cement (manufactured to BS 12), natural aggregate (granite), steel slag aggregate, natural fine aggregate (river sand) and water. The maximum size of coarse aggregate considered was 19mm and minimum size of aggregate considered was 12.5mm while fine aggregate used passed through a 2.36-mm sieve and retained on 63-μm sieve. Steel slag aggregate used in this investigation was collected from the slag deposit in the yard of Phoenix Steel Mill, Ogijo, Ogun state, Nigeria. The parent Steel Slag was crushed with milling machine in the laboratory into aggregates sizes not greater than 19mm grading of the aggregates (fine and coarse) and SSA were conducted in accordance with BS 1377 Parts 1 and 2 while the aggregate crushing strength value was determined as specified in BS 812-110: 1990. The sizes of the steel bar used are 6mm and 12mm for stirrups and main bar respectively. Portable water was used for the mixing.

2.2. Mix Proportion and Methods

Five different mixes were prepared with varying percentage contents of SSA, between 0% and 100% at interval of 25% as substitute for crushed granite. The concrete mix of 1:2:4 and water-cement ratios of 0.55 and 0.65 were used. Workability of the fresh concrete was determined using Slump test and Compacting Factor Test as described in BS 1881 (1996).

A total of Ninety (150mm x 150mm x 150mm) cubes were cast for both water-cement ratio considered and after 24 hours the concrete cubes were de-moulded and immersed in a water tank in the laboratory for a curing period of 7, 14, and 28 days. At the end of each curing period, the specimens were weighed and tested for compressive strength and density using the procedure described by BS 1881 (Part 3). Nine reinforced corbel specimens of sizes 125 mm x 250 mm x 550 mm were cast and tested for shear friction at ages 7, 14 and 28days.

The procedure of Shear friction test is listed below;

1. The short column specimens (100 x 500mm) were de-moulded 24 hours after casting and cured with wet jute bag until the age of test.
2. At each curing age of 7, 14 and 28 days, the wet jute bags were removed and the specimens left to dry for two (2) hours before being tested,
3. The short column is marked for the position of the supports and was placed in alignment with the Y-axis centroid of the hydraulic jack and fixed support.
4. Axial load is applied through the hydraulic jack at intervals of 10kN, until the initial cracks were noticed. Flexural crack patterns are highlighted with chalk on the failed column for clarity. The dial gauge readings on hydraulic jack are zeroed at the initial loading process, only incremental load as a result of the hydraulic jack is noted against the crack pattern until final failure i.e. prone crack is noticed.
5. The readings of applied axial loads are recorded for different specimens against time taken for the specimen to shear.

3. RESULTS AND DISCUSSION

3.1. Physical Properties and Particle size distribution of SSA and natural aggregate

The crushed Steel slag was sieved through the 25 mm sieve size and the resulting aggregate particles were again passed through the 4.75 mm sieve size. The left over particles from the crushed SSA was discarded. The sieve analysis test conducted on the aggregates which include granite, sharp sand and steel slags are presented in Figure 1 below.

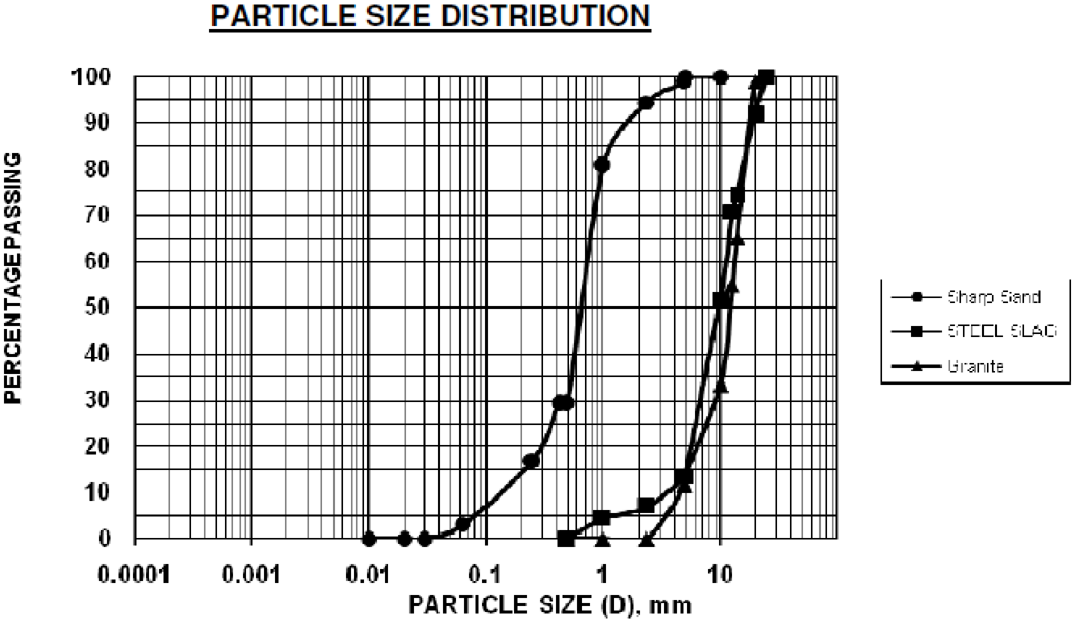

Figure 1. Sieve Analysis Graph of Granite, Sharp Sand and Steel Slag

From the results above, with the fine aggregate having a Cu value of 4.00 and a Cc value of 1.78, it can be classified according to Unified Soil Classification as a Well Graded medium to coarse sand. The coarse aggregates; granite and steel slag, can be classified as medium graded coarse aggregate with Cu value of 2.10, Cc value of 1.54 and Cu value of 3.37, Cc value of 1.19 respectively. A fineness modulus of 4.09 was obtained for the sand; this lies around the boundary for fine aggregate. The granite and steel slag also have a fineness modulus that fall between 2.85 – 3.86, which implies that the granite and steel slag can be classified as coarse aggregates.

Table 1. Physical Properties of Steel Slag Aggregate and Granite

Physical Properties	Steel Slag Aggregate	Granite
Specific gravity	2.47	2.85
Coefficient of uniformity	3.37	2.10
Coefficient of	1.19	1.54
Moisture content	0.64	0.38
Water Absorption	3.52	0.55

3.2. Effect of Steel slag concrete on Workability

Table 2. Workability Test Results of SSA Concrete.

SSA	Slump (mm)		Compaction Factor	
	0.55w/c	0.65w/c	0.55w/c	0.65w/c
0	138	146	0.8179	0.8307
25	106	115	0.9051	0.9216
50	23	30	0.9306	0.9464
75	5	8	0.9460	0.9657
100	2	2	0.9540	0.9679

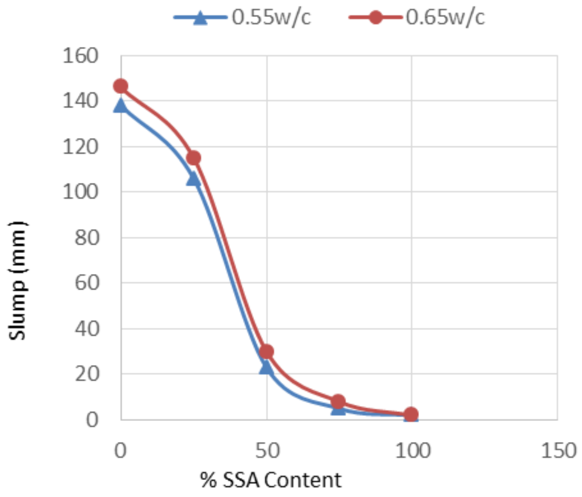

Figure 2. Slump Test Result of SSA Concrete

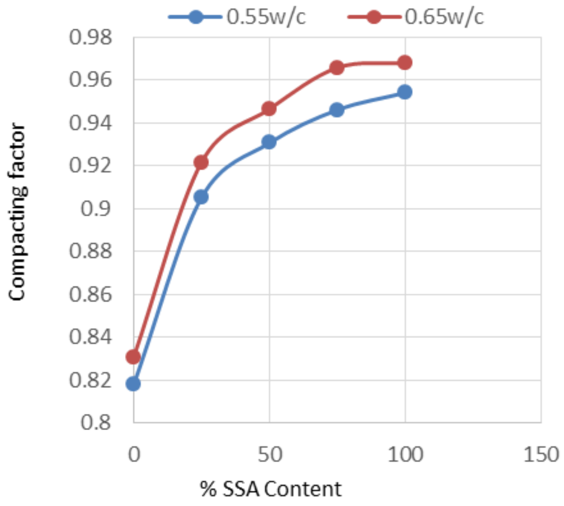

Figure 3. Compacting Factor of SSA Concrete

The results of the slump test show that the value of the slump reduces with increase in the percentage of slag in the concrete for both water-cement ratios considered. The highest slump value recorded was 146 mm (Table 1) for normal concrete (0% slag content), and at 0.65 water-cement ratio. The higher water-cement ratio, 0.65, gave higher slump values than 0.55, for all the batches except at 100% slag content. This trend as shown in Figures 4 and 5, was also observed in the compacting factor test results. The decrease in workability with increasing percentage replacement level of natural coarse aggregate with slag aggregate may be attributed to the rate of absorption of water and rough surface texture of the slag. The pore structure of the slag leads to a significant increase in water absorption and therefore reduces the amount of water available to hydrate the cement.

3.3. Effect of Steel Slag on Density

The results obtained for density of SSA concrete are as shown in Figures 2 and 3 for the two water-cement ratios (0.55 and 0.65) considered. Density obtained at 0.65w/c at 28 days curing age was 2574, 2492, 2256, 2155 and 2023kg/m^3 for 0%, 25%, 50%,75% and 100% respectively. Similarly, for 0.55 w/c ratio and at 28days curing age, the density obtained are 2489, 2445, 2400, 2356 and 2280 kg/m^3 for 0%, 25%, 50%,75% and 100% respectively.

It can be observed that the density of SSA concrete increased as the curing age increased as in normal concrete. At higher water-cement ratio of 0.65, density of SSA concrete increased compared to the 0.55 water-cement ratio, this is in order with the workability results which shows that at higher water-cement ratio, steel slag aggregate concrete is more workable. Increased workability increases the ease of compaction which in turn increases density. For both water-cement ratios considered and compared to normal concrete, density of SSA concrete reduced as the percentage replacement of natural coarse aggregate increased. It is noted that SSA has lower density compared to normal concrete. The maximum density recorded for steel slag aggregate concrete was 2492 kg/m^3 at 25% SSA content and 0.65 w/c ratio.

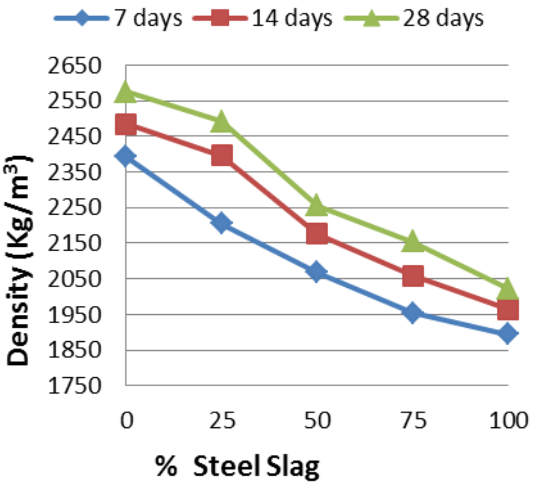

Figure 4. Average Density of SSA Concrete at 0.65 w/c ratio

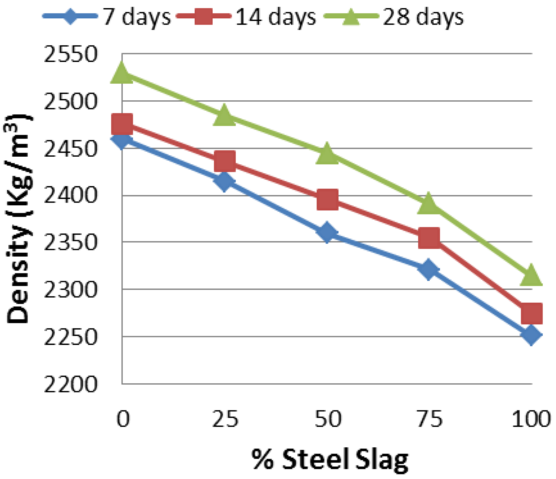

Figure 5. Average Density of SSA Concrete at 0.55 w/c ratio

3.4. Compressive Strength of concrete blended with Steel Slag Aggregate

The compressive strength of slag concrete cubes at 28 days are presented in Table 2 and Figures 6 & 7. The results showed that the normal concrete (0% SSA) has the highest compressive strength of 33.65N/mm^2 at 28 curing days. The highest compressive strength recorded for slag concrete was 31.89N/mm^2 (0.65w/c) at 25% slag content while the lowest was 20.44N/mm^2 (0.55w/c) at 100% slag content. This shows that slag concrete can attain adequate strength for structural use.

Compressive strength was found to decrease as the percentage SSA content increases in the concrete. This may be attributed to the low workability of the mix and the aggregate strength which is lower compared to natural aggregate. For both normal and SSA concrete, strength increases at higher water-cement ratio of 0.65 than at 0.55. The percentage increase in strength at 0.65 w/c compared to 0.55w/c at 0%, 25%, 50%, 75% and 100% are 1.5%, 0.79%, 1.04%, 1.01%, 1.04%. Also, for both SSA and normal concrete, strength increases as the curing age increases.

Table 3. Average Compressive Strength of Steel Slag Aggregate Concrete

	Average Compressive Strength (N/mm^2)									
SSA (%)	0%		25%		50%		75%		100%	
Days	0.55w/c	0.65w/c	0.55w/c	0.65w/c	0.55w/c	0.65w/c	0.55w/c	0.65w/c	0.55w/c	0.65w/c
7	28.15	29.69	26.68	28.31	24.63	25.44	23.48	23.67	18.44	19.98
14	30.58	31.20	28.62	29.11	26.91	26.95	24.78	24.85	19.20	20.31
28	33.65	34.15	31.64	31.89	28.60	29.76	25.64	25.81	20.44	21.24

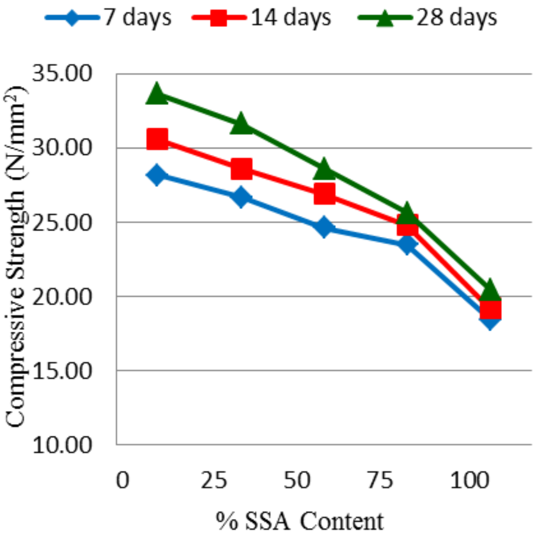

Figure 6. Average Compressive Strength of SSA Concrete at 0.55w/c

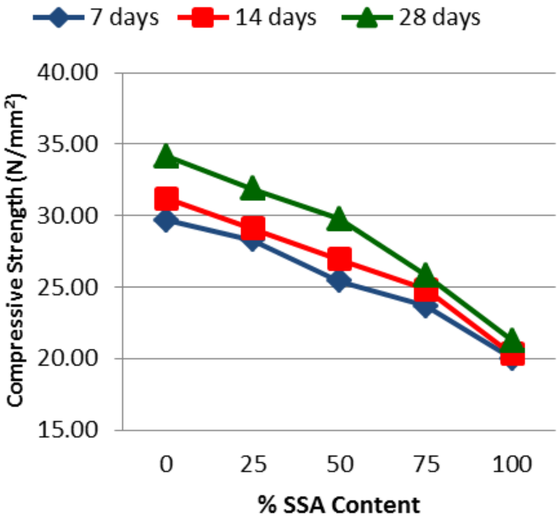

Figure 7. Average Compressive Strength of SSA Concrete at 0.65w/c

3.5. Effect of Steel slag on Shear friction of Concrete Corbel

Shear friction is a parameter that estimates the maximum shear force transmitted across a plane where crack has occurred in a concrete member. From the shear capacity test, continuous incremental loading of 10kN generated a number of random fine cracks which developed at the tension face of the beams. As the load increases, these cracks gradually increased in number and length. The cracks changed direction, by-passing the more resistance grains of slag in the matrix and gradually form a single major crack which propagates approximately along a line joining the loading point to the support.

All tested specimens failed in shear; this being characterized by the formation of cracks along shear stress zone. The first crack originated along the applied load axes of the shear plane, the crack pattern is almost similar in all the corbel specimens. At higher loads, it was observed that already formed cracks got widened with addition of new cracks.

As the corbels age, the time taken for formation of crack under load increased for all the concrete batches, and as the load increases the time taken for crack formation reduces.

The shear friction capacity of the concrete in terms of time taken for it to shear after a certain magnitude of load is applied is presented in table 4 below. It can be seen that the time reduces as the load increases for all the batches and at all concrete ages considered. Also, the time taken for the concretes to shear increases as the concretes age. At 28days, normal concrete has the best shear friction capacity, having the highest time taken under a 1ton load before shear to be 39.21 seconds. The shear friction capacity decreases as the percentage of slag increased in the concrete. It can be observed that the trend of the shear friction capacity of the slag concrete is very similar to that of compressive strength, this shows that the reduction in shear friction capacity due to aggregate factor is considerable. The transmission of forces across a crack takes place at numerous contact areas between the aggregate particles embedded in the crack faces and the matrix on the opposite face of the crack. This explains the fact that concrete quality play an important role in shear friction because the matrix strength depends on it.

Table 4. Summary of Load−Time Result for SSA Corbel Beams

Load (kN)	Time (seconds) 7 days curing				
	0%	25%	50%	75%	100%
10	29.13	28.78	18.12	17.91	16.39
20	24.99	20.83	14.73	12.46	11.56
30	20.78	18.13	12.61	11.14	9.90
40	15.40	13.18	10.47	9.38	7.82
50	11.69	10.48	7.93	6.04	5.28
60	7.84	6.21	4.67	3.29	2.43
70	2.53	2.47	1.47	1.35	1.06
Load (kN)	Time (seconds) for 14 days curing				
	0%	25%	50%	75%	100%
10	28.67	23.64	19.69	18.35	17.64
20	26.06	20.93	18.24	16.43	13.84
30	25.34	17.83	16.24	15.79	11.76
40	18.46	14.12	13.63	12.10	9.42
50	14.63	10.74	10.54	9.14	7.22
60	9.07	6.13	6.0	5.82	4.45
70	5.88	3.25	3.03	2.85	2.16
Load (kN)	Time (seconds) for 28 days curing				
	0%	25%	50%	75%	100%
10	39.21	33.60	31.23	25.66	24.26
20	35.15	31.06	27.19	22.53	21.41
30	27.64	27.57	23.50	19.93	18.38
40	23.89	20.34	19.05	17.18	13.98
50	16.33	13.89	16.35	14.22	9.68
60	12.45	10.68	10.89	10.13	6.32
70	8.21	6.31	6.01	4.59	3.57

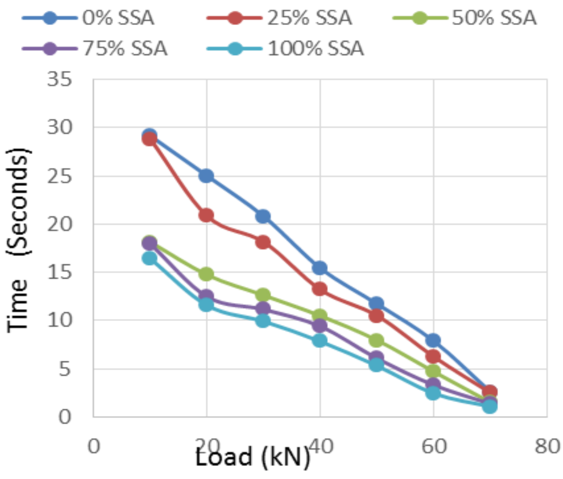

Figure 8. Time-Load Curve of SSA Concrete at 7 days Curing Age

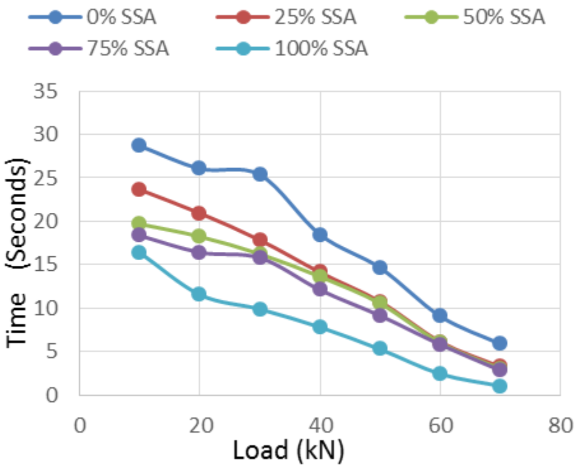

Figure 9. Time-Load Curve of SSA Concrete at 14 days Curing Age

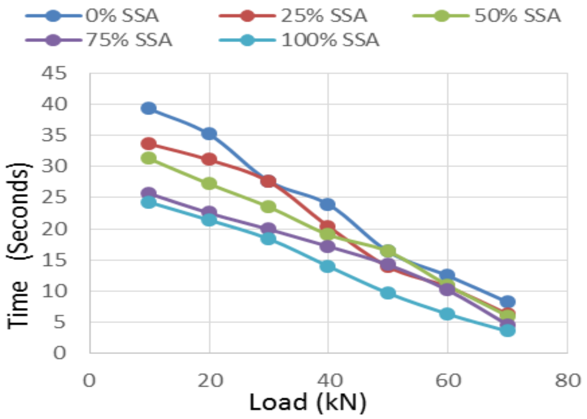

Figure 10. Time-Load Curve of SSA Concrete at 28 days Curing Age

Figure 11. Shear Failure along plane of Steel Reinforced Corbel during Loading Test

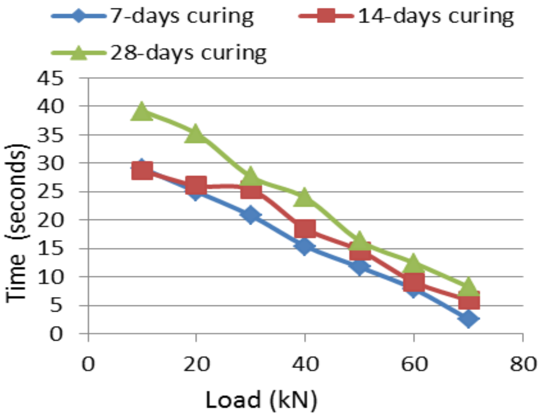

Figure 12. Time-Load Curve of normal Concrete

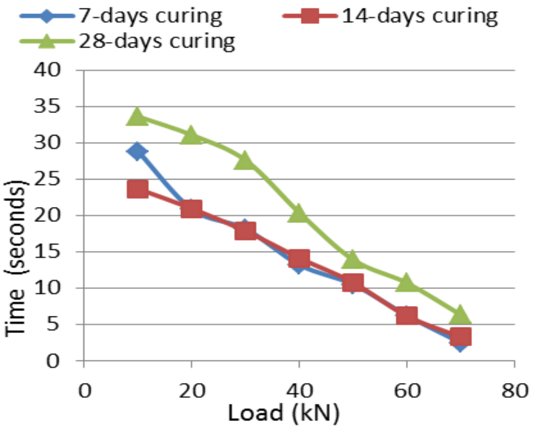

Figure 13. Time-Load Curve of SSA Concrete at 25% SSA content

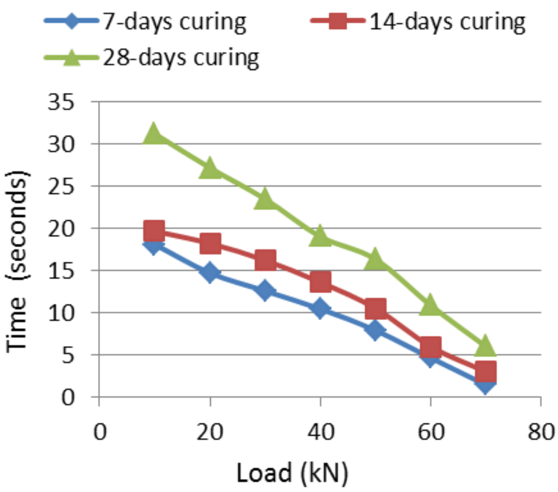

Figure 14. Time-Load Curve of SSA Concrete at 50% SSA content

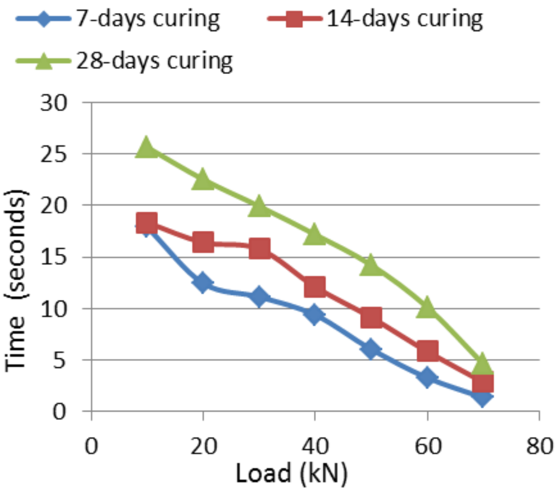

Figure 15. Time-Load Curve of SSA Concrete at 75% SSA content

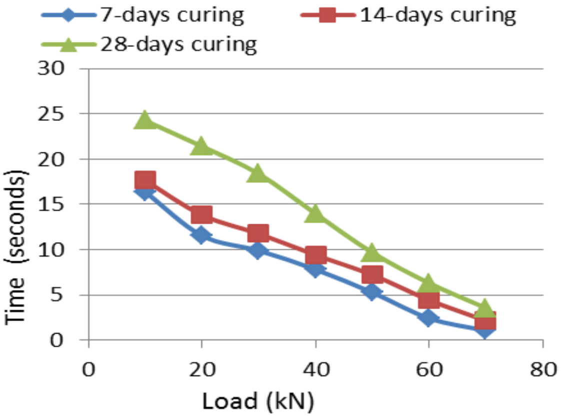

Figure 16. Time-Load Curve of SSA Concrete at 100% SSA content

4. CONCLUSIONS AND RECOMMENDATIONS

From the results of the various tests conducted, the following conclusions can be drawn:

i. SSA concretes are less workable than normal concrete, but they can achieve good workability up to 50% replacement level.
ii. Density of SSA concrete decreases as percentage replacement increases and at higher water-cement ratio of 0.65, density of SSA concrete increased compared to the 0.55 water-cement ratio. The density of 2492 kg/m^3 was recorded for slag concrete at 25% slag content at 0.65 water-cement ratio.
iii. The highest compressive strength recorded for slag concrete was 31.89 N/mm^2 (0.65w/c) at 25% slag content while the lowest was 20.44 N/mm^2 (0.55w/c) at 100% slag content. This shows that slag concrete can attain adequate strength for structural use. Compressive strength was found to decrease as the percentage SSA content increased in the concrete.
iv. Concrete made with 25% SSA has the optimum shear-friction capacity than other replacement levels of SSA and performs better in shear.

The SSA can be recommended for use as coarse aggregate in concrete for structural elements up to 25% replacement level of crushed granite in concrete matrix. It can also be used in low-cost housing where high cost of building materials, especially granite contributed to high cost of project delivery. The use of SSA in concret shall help reduce environmental pollution and degradation caused by mining of granite, thereby turning our waste in environment to wealth.

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