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PERFORMANCE OF STEEL SLAG AGGREGATE CONCRETE WITH VARIED WATER- CEMENT RATIO

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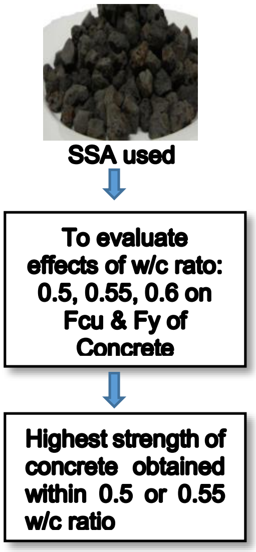
Graphical abstract



Abstract

Several thousands of tons of electric arc furnace slag (EAF) slag generated in Nigeria are yet to be utilised for construction; perhaps as a result of inadequate technical details for its use. The present study has evaluated the effects of varying water-cement ratio on workability and strength of locally generated steel slag aggregate (SSA) concrete. Tested samples include 150 mm concrete cubes and cylinder samples with 150 mm diameter and 300 mm height respectively. SSA was substituted in increments of 20% by weight of granite until 100% mix, while w/c was varied at 0.5, 0.55 and 0.6. Workability of fresh concrete was evaluated through slump test. Hardened concrete cubes and cylinders were subjected to compression and split tensile tests respectively, after 7, 14 and 28 days curing periods. Slump values obtained were in the range of 50 – 90 mm for all the mixes, which represented a S2 slump. Compressive strength and tensile strength increased with age and increasing slag substitution. A strength of 25 MPa for normal weight concrete was achieved at 28 days with 20% SSA substitution, only within 0.5 and 0.55 w/c ratio. However, result obtained for concrete mixes with 60% SSA and above at 28 days established that these mixes are good for production of high strength concrete.

Keywords: Workability, steel slag, concrete, compressive strength, tensile strength

1.0 INTRODUCTION

Solid wastes from industrial and construction activities currently constitute high percentages of alternative materials for concrete production worldwide. In past years, recycled aggregates, scrap tyres, glass and ceramic wastes [1], and some other materials [2] have been investigated. Steel slag, a residue of steel production process is one of those materials researchers have explored for its beneficial use. Huge amount of steel slag are produced, ranging from large boulders to fines; also it contains silicates and oxides of unwanted elements in steel chemical composition.

The oxides present in steel slag are problematic and hazardous to the environment. Moreover, factories pay so much cost for the disposal of these materials, which in addition have a negative impact on the environment. Unfortunately, steel slag is almost non-recyclable, however its recent consideration for construction is absolutely a gain. In 2015, US geological survey (USGS) [3] estimated about 170 to 250 million tons of steel slag to be produced worldwide, based on typical ratios of slag to crude iron and steel output. In Nigeria, thousand tons of steel slag are generated yearly but yet to be utilised in construction; they are mostly disposed in dumpsites and except occasionally, when it is used as filling materials for potholes and failed spot of earth roads. Generally, steel slag are categorized into basic oxygen furnace (BOF) slag and electric arc furnace (EAF) slag; the classification is based on the raw materials and production process. Recent research findings on different platforms have identified steel slag as a viable replacement for aggregate in concrete [4, 5] On the other hand, EAF slag was reported as a sustainable material for: soil modification [6, 7]; and also in bituminous pavement admixture [8, 9, 10]. Also the properties of steel slag as a cement additive has been explored [11], whereby it enhanced the quality of cement. As against the routine disposal of this kind of waste, a more beneficial use of steel slag is needed for production of concrete in an eco-friendly manner, such that resource and energy consumption are minimized [12, 13, 14].

Previously, studies have dwelt on the use of steel slag as partial replacement for the scarce natural aggregates. An investigation on the utilization of fine recycled aggregates in concrete with fly ash and steel slag was done by Anastasiou *et al*., 2014 [15]. Their study revealed that 50% cement replacement with high calcium fly ash and mixture of steel slag and recycled aggregates resulted in concrete of adequate strength. When compared to natural aggregates, steel slag possess high density and water absorption quality than granite; in addition the durability characteristics of steel slag cement concretes are better than those of crushed limestone aggregate concrete [16]. Numerous researchers have investigated the mechanical properties and durability of steel slag concrete [17, 18, 19]. Their studies showcased an appreciable results in strength of concrete tested.

In addition, concrete with steel slag was reported to have a good post-fire residual strength [20] than the normal concrete [21]. Though, Awoyera *et al*., 2014 [22] buttressed the fact that maintaining designed concrete cover to reinforcement enhances fire resistance of concrete.

Meanwhile Lee and Lee, 2013 [23] investigation dwelt on the setting and mechanical properties of alkali-activated fly ash/slag concrete manufactured at room temperature, it was revealed that setting time decreased as the amount of slag and the concentration of the NaOH solution increased. However, the use of steel slag reduces the workability of concrete but strength development of concrete is enhanced when slag is incorporated [24]. Conversely, volumetric instability has been identified as one major setback in the utilization of steel slag for concrete production [25, 26]. This defect occurs as a result of hydration of free calcium (CaO) and magnesium (MgO) oxides contained in steel slag. Literatures revealed that stockpiling and exposures of steel slag to weather for about 8 months reduce these oxides and consequently its expansive nature.

In addition, Frias *et al*., 2010 [27] articulated 45 days ageing period for reduction of expansive characteristics in steel slag with low concentration of expansive oxides. In Nigeria situation, the strength of locally produced steel is lower than that of imported ones; and the same might be case for steel slag generated from such steel productions. This study is focused to examine the influence of SSA generated from local steel industry, and their substitution in steps of 20% by weight of natural aggregate on the workability and strength of concrete, while the water/cement ratio is also varied.

2.0 MATERIALS AND METHODOLOGY

Both normal aggregate and steel slag of nominal size 12.7 mm were used in the preparation of all mixes. This aggregate size was considered because SSA sizes normally will not impair the strength of concrete [28]. Black boulder size steel slag was obtained at a dumpsite located along the Ota – Idiroko road, Ota, where it has been stockpiled for over a period of 10 months. Thereafter, the steel slag were stored in the Covenant University concrete and material testing laboratory for another two months, so as to subdue the free oxides concentration, thus in alignment with the findings of Juckles, 2003 [29].

Chemical composition of the steel slag used, shown in Figure 1, was determined and corroborated with another established results by Yi *et al*., 2012 [30]. A comparison of the results indicated that Free CaO and MnO concentrations are minimal which implied that these expansive oxides are loss during exposure of the steel slag. The gradation and processing of these aggregates were obtained following BS EN 16236 [31] standard procedure. SSA was introduced in varying proportions as partial replacement for granite, that is, 0%, 20%, 40%, 60%, 80% and 100%; thus the corresponding mixes are denoted as SS-0, SS-20, SS-40, SS-60, SS-80 and SS-100 respectively.

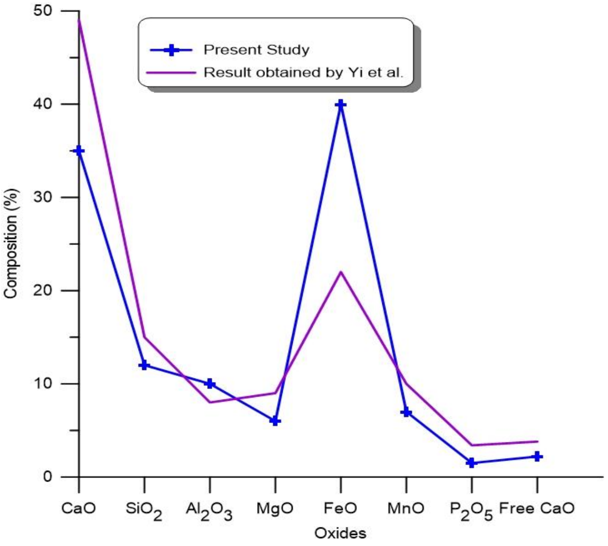


Figure 1 composition of steel slag used

Natural river sand of nominal size 2 - 4 mm was utilized as fine aggregate for all mixes. The Ordinary Portland Cement used satisfied the requirements of Standard Organization of Nigeria NIS 444-1 [32].

Thus, constituent material were batched by weight and mixed with 1:2:4 ratio of cement, sand and aggregate, however the water-cement ratio (w/c) was varied at 0.50, 0.55 and 0.60. Concrete sample preparation and testing were performed at the material and structures.

Laboratory of Department of Civil Engineering, Covenant University, Ota. The workability of the concrete mixes were measured according to the provision of BS 1881-part 102 1983 [33].

Conventional concrete mix was produced with the same specifications and used as control. Thus, combinations of all the materials were used in different concrete mixtures in order to determine the effect of each parameter on workability and strength. All concrete mixes were performed manually. Concrete cubes of dimension 150 mm x 150 mm x 150 mm and cylinders of 150 mm diameter and height of 300mm were produced. Hardened concrete cubes and cylinders were demoulded after 24 hours of casting, and subsequently cured in a water tank. Concrete cubes and cylinders were subjected to uniaxial compression and split tensile tests respectively, after 7, 14 and 28 days curing period, using YES-2000 digital display compression machine. Compression and split tensile tests were performed according to the provisions of BS 1881 Part 116, 1983 [34] and BS 1881 part 117, 1983 [35] respectively.

3.0 RESULTS AND DISCUSSION

The use of steel slag as partial replacement for conventional aggregate in concrete, with water-cement ratio varied has been investigated. Figure 2 presents the slump test results for the fresh concrete. In all the mixes, the behaviour of the concretes in slump followed the same pattern, in that, slump decreased until about 60% steel slag substitution before it increased. Though the slump obtained for the mixes satisfied the S2 (50 – 90 mm), but in essence, the increased weight of steel slag, unlike granite, contributed to the deformation seen in the fresh concrete as slag content was increased. Smoothness of the SSA surface minimizes friction at the surface of the slump cone and the concrete, and thus enhancing the slump.

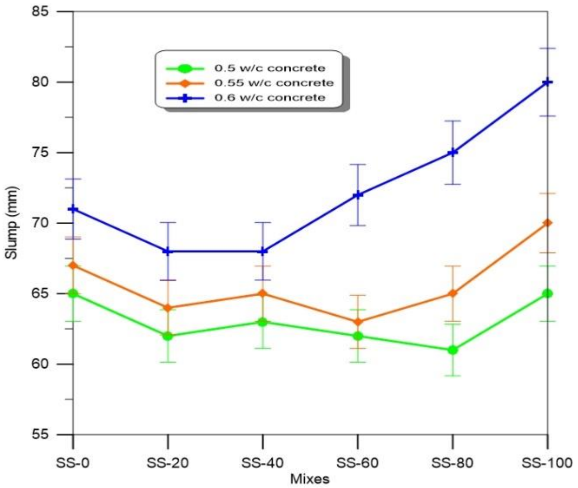


Figure 2 Slump tests for all mixes

Compressive strength tests were carried out after 7, 14 and 28 days of curing the concrete cubes. Figures 3 – 5 shows the compressive strength development of the mixtures up to 28 days, for concretes with 0.5, 0.55 and 0.6 w/c respectively. Variation of compressive strength with SSA mixes are represented in Figures 3a, 4a and 5a, while Figures 3b, 4b and 5b represent the variation of compressive strength with age. As expected, compressive strength increased with age and increasing SSA content. However, the step substitution of SSA in 20% increment by weight is interesting. For a 0.5 w/c concrete mix, SS-20 mix developed roughly 13% strength than SS-0, that is, natural concrete, at 28 days curing period. Variation in strength of SS-0 and SS-100 measured represented a 77.57 % strength gain. Basically, the increasing percentage substitution of granite with steel slag improved the compressive strength of the concrete. Early strength gained in the SSA concrete was significant. Moreover, the influence of w/c ratio cannot be overemphasized. In the three categories of w/c ratio adopted, it is clear that a rapid strength development can be obtained in concrete by reducing the w/c ratio; a similar study on natural concrete [36] corroborated this.

The recommended 25 MPa strength [34] for a normal weight concrete at 28 days was achieved with 20% SSA substitution by weight of natural aggregate using 0.5 and 0.55 w/c ratio. However, result obtained for concrete mixes with 60% SSA at 28 days has established that SS-60 mixes and above are good for production of high strength concrete.

It is noteworthy that failure pattern in SSA concrete cubes differs from the conventional concrete; in the formal, failure cracks are approximately parallel to the direction of the applied load whereas the latter undergoes an explosive mode of failure.

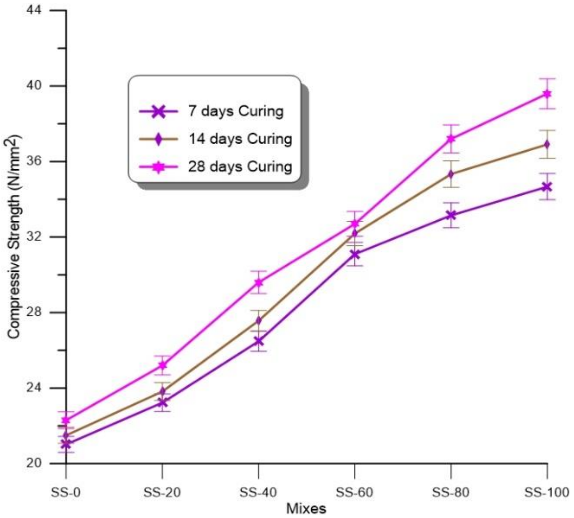


Figure 3a Compressive strength of concrete with 0.5 w/c ratio mixes with steel slag content

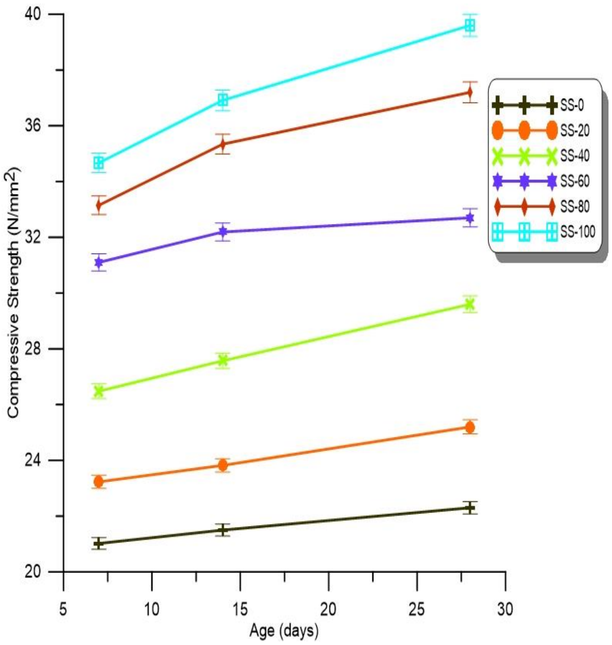


Figure 3b Compressive strength of concrete with 0.5 w/c ratio mixes developed at different ages

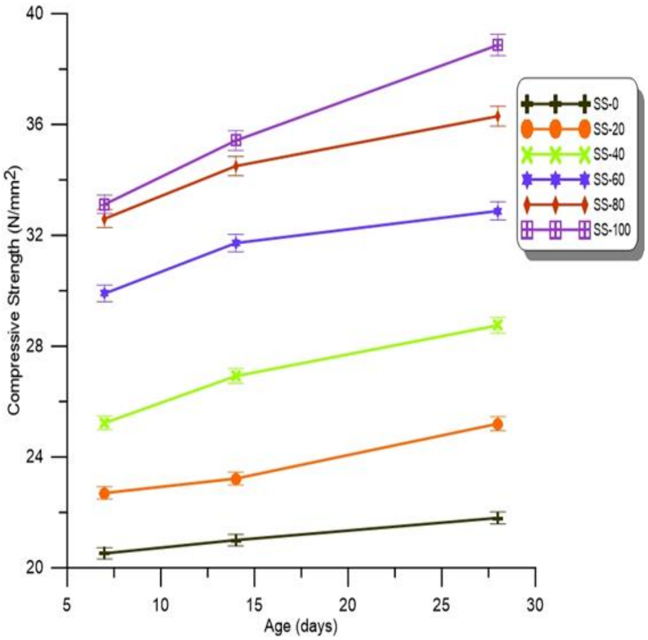


Figure 4b Compressive strength of concrete with 0.55 w/c ratio mixes developed at different ages

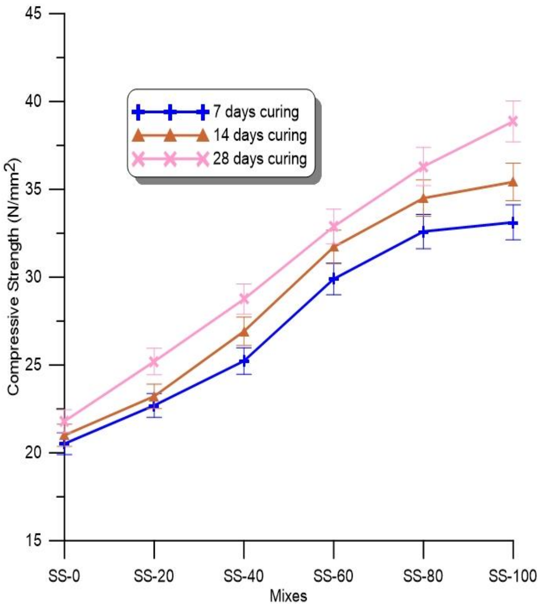


Figure 4a Compressive strength of concrete with 0.55 w/c ratio mixes with steel slag content

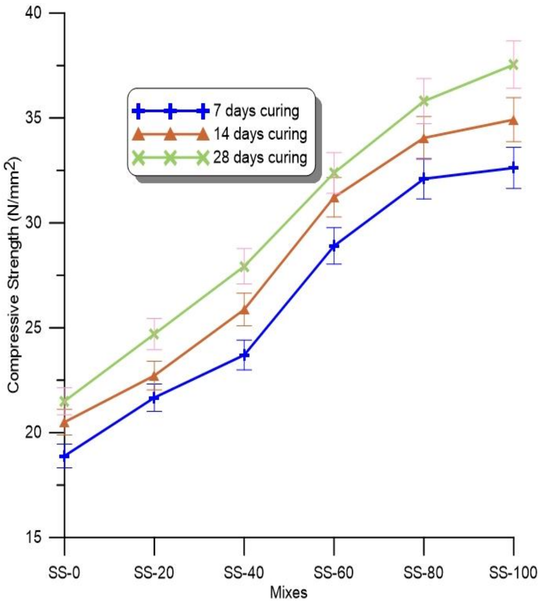


Figure 5a Compressive strength of concrete with 0.6 w/c ratio mixes with steel slag content

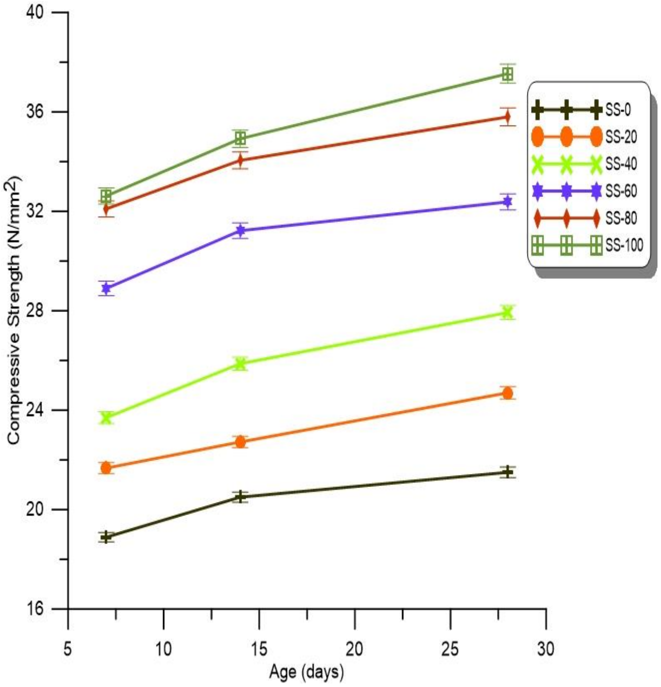


Figure 5b Compressive strength of concrete with 0.6 w/c ratio mixes developed at different ages

Split tensile strength of the concrete mixes have been evaluated. The test evaluates the load at which the concrete members may crack. Figures 6 – 7 present the split tensile strength at different ages of testing for mixes with 0.5, 0.55 and 0.6 w/c ratio. Tensile strength increased with age of concrete, and increasing SSA content as indicated in the bar chats. However, the tensile strength decreases with increasing w/c ratio.

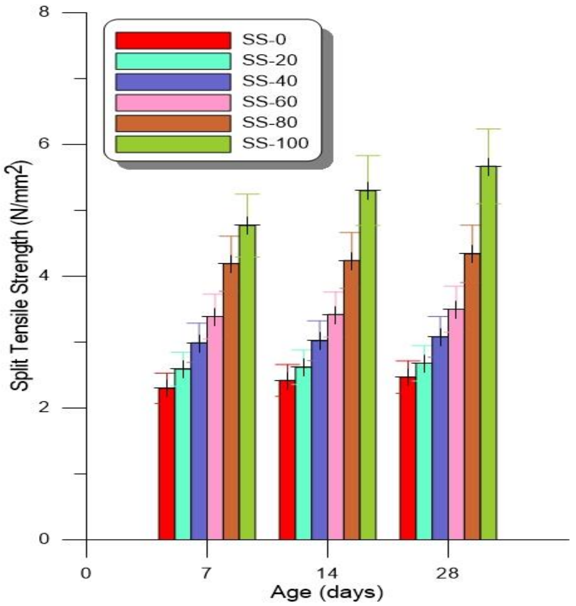


Figure 6 Split tensile strength for concrete made with 0.5 w/c ratio at different ages

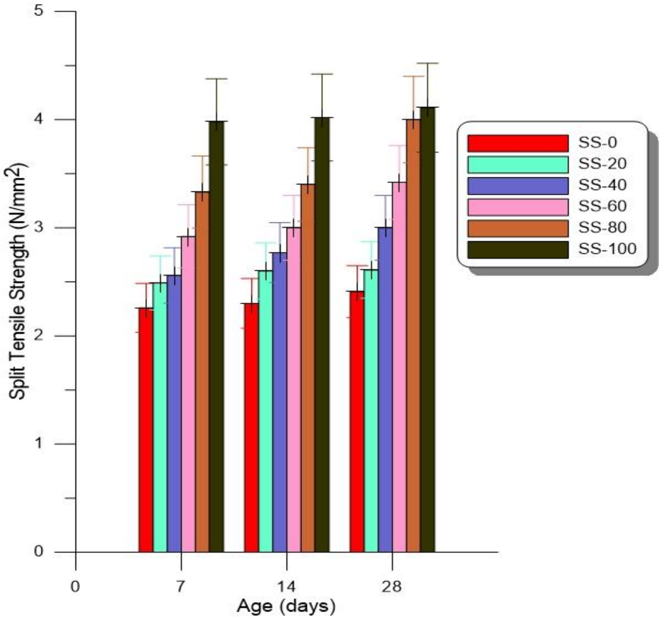


Figure 7 Split tensile strength for concrete made with 0.55 w/c ratio at different ages

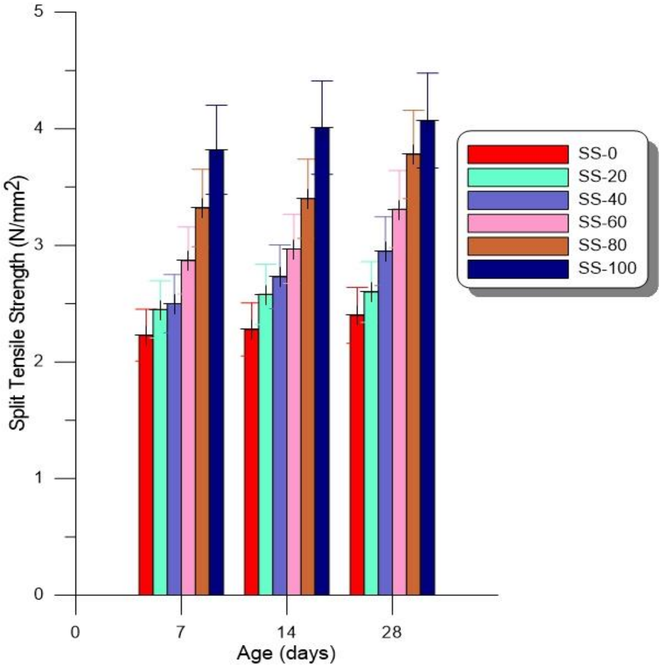


Figure 8 Split tensile strength for concrete made with 0.6 w/c ratio at different ages

4.0 CONCLUSION

Based on the results presented in this paper, the following conclusions can be drawn:

1. Practically, it was tedious to perform a manual mixing with SSA concrete mixtures, although the slump obtained for the mixes satisfied the desired S2 (50 – 90 mm). Basically, the increased weight of steel slag, unlike granite, contributed to the deformation seen in the fresh concrete as slag content was increased. A 0.6 w/c ratio is recommended for concrete with SSA in order to enhance workability of the concrete.

2. Locally produced steel slag possesses good properties like the natural aggregates. Steel slag needs to be crushed under controlled conditions in order to ascertain its suitable grading for construction need.

3. Just like the normal weight concrete, it was established that a rapid strength development can be obtained in SSA concrete by reducing the w/c ratio.

4. Both compression and split tensile tests produced an appreciable results. Consequently, it is viable that normal and high strength concretes can be made with 20% and 60% steel slag replacement of normal aggregate respectively.

5. Utilization of steel slag as coarse aggregate is a sustainable approach to preserving the depleting natural aggregates. With the increasing cost of conventional concrete; SSA concrete constitute the potential for provision of affordable housing in low-income communities.

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