# Influence of Electric Arc Furnace (EAF) Slag Aggregate Sizes on the Workability and Durability of Concrete

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**Abstract—The construction industry has been identified as one of the largest consumer of non-renewable resources. Meanwhile, the unused materials are continually disposed in landfills and dumpsites. As a result, adoption of industrial solid wastes for use as a construction material remains pertinent in the creation of a green environment. The present study focused on the influence of EAF steel slag aggregate (SSA) sizes on the workability and durability of concrete. Concrete mixes in 1:2:4 ratios of cement, sand and SSA; batched by weight, and a water cement ratio of 0.6 were considered. However, a control mix using normal aggregate (NA) was made in order to evaluate the variation in properties of the concretes. The study utilised SSA and NA sizes of ½ inch (12.7 mm), 3/8 inch (9.54 mm) and ¾ inch (19.05 mm) respectively. All testing were conducted under room temperature, adopting procedures recommended in BS standards. For all the aggregate sizes considered, SSA produced an appreciable 28 day compressive strength than the NA concrete. However, the NA concrete possess good workability than the SSA concrete.**

**Keywords-** steel slag, aggregate, compressive strength, concrete, workability

## I. INTRODUCTION

In recent years, constituent materials for concrete production such as aggregates and cement have become expensive due to depletion of natural quarries and more so, as a result of their incessant utilization in construction [1]. Moreover, the consistent exploitation of natural material for construction poses a serious challenge on the sustainability of the environment [2, 3]. From the perspective of energy saving and conservation of natural resources, management of the environment from the construction industry context currently constitutes a global concern. US Geological Survey [4] revealed that the production of crushed stone in the past twenty-five years has increased at an average annual rate of about 3.3%. Thus, by their projection, the amount of crushed stone to be produced till the year 2020 will equal the quantity of all stone produced during the previous century, which will amounts to about 36.5 billion metric tons. These projections suggest that vast quantities of crushed stone, sand and gravel will be needed in the future; however, the present available resources is insufficient to cater for that amount of materials. Moreover, it was also understood that the aggregate quarry and asphalt operations are energy intensive [5]. Therefore, the detrimental consequence of overexploitation of natural quarries on environmental degradation demands urgent attention in the built environment. An alternative choice of ecofriendly materials are needed in construction industries in order to address issues related to sustainability of the environment.

In the foregoing, considering the deficiencies of continual exploitation of natural aggregates; researches are currently motivated towards the beneficial use of solid waste materials as partial substitutes for the convectional aggregates. Usually, solid waste materials are utilised as filling materials or otherwise disposed in landfills. As a result, numerous health treats and environmental hazards are emanated such as contamination of surrounding soil and water, and more so, biodiversity is affected [6]. However, several research interests are aroused in the quest to reduce the consumption rate of natural aggregates. Studies have suggested the use of locally available onsite materials like mud [7], for construction of affordable houses in peri urban cities. Likewise, other investigations are focused on appropriate means of improving the compressive strengths of laterite [8], which are dominant in most parts of West African Countries. On the other hand, the use of waste newspaper and office paper for production of light weight concrete was investigated by [9]. From their study, papercrete was recommended to be an effective and sustainable material for the production of lightweight and fire-resistant hollow or solid blocks to be used to make partition walls of especially high-rise buildings.

Over the years, waste materials such as tyres, glass, ceramic tiles and steel slags have been investigated [10-12], in order to determine their suitability as coarse aggregates in concrete. Most research results revealed an appreciable strength gain in concrete when the waste materials are partially substituted for natural aggregates. According to [13], coarse aggregate fraction is that material retained on 4.75 mm (No 4) sieve, while the fine aggregates fraction is that passing the same sieve.

In furtherance, this present study is focused on the evaluation of the influence of steel slag aggregate sizes on the workability and durability of concrete. Steel slag is a known by-product produced during the conversion of iron ore or scrap iron to steel. The major categories of steel slag, based on its raw materials and production process includes basic oxygen furnace (BOF) slag and electric arc furnace (EAF) slag.

An estimate made by [4], revealed that the world annual production of steel slag is estimated to range between 90 - 135 million metric tons. Still, the potential of its full beneficial applications are yet to be explored. In Nigeria for instance, larger percentage of the steel slag generated annually are mostly disposed or used as filling pot-holes at failed road spots. Further, the chemical composition of steel slag minerals have been investigated by researchers. Shih et al. [14], articulated the mineralogical composition and chemical components of steel slag as includes the following: Olivine, merwinite, di-calcium silicate, tricalcium silicate, tetra-calcium aluminoferrite, di-calcium ferrite, solid compound of CaO–FeO–MnO–MgO, and free CaO. Still according to [14], steel slag mineralogical composition changes with its chemical components. Typical range of values for steel slag chemical composition for EAF and BOF slag, obtained by [15] is graphically represented in Figure 1.

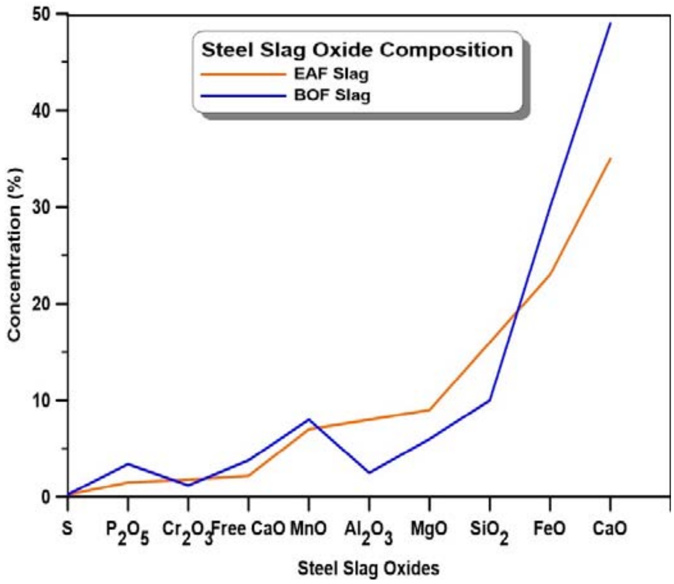


Figure 1: Typical Steel Slag Composition

Moreover, the presence of high free CaO content in steel slag [16,17], was attributed to causing volume expansion problems, which limits it use for construction. But this effect could be controlled by stockpiling steel slag or expose it to weather for a period of about 6 - 12 months before use [18]. However, steel slag have been used to produce construction materials [19-21], such as cementitious pastes, bricks and concrete. Similarly, [22] used steel slag to produce combined alkali-slag paste materials.

Despite having extensive research about the use of steel slag as a construction material, none of the reviewed literatures has considered the influence of SSA sizes on concrete properties. Hence, this present study aims to determine the workability and durability of SSA concrete.

## II. MATERIALS & METHODS

This study aims to evaluate the influence of SSA sizes ½ inch (12.7 mm), 3/8 inch (9.54 mm) and ¾ inch (19.05 mm) on the workability and durability of concrete. Black riprap sized steel slag samples used for this research, were collected from a stockpiled spot at Nigerian Federated Steel Ltd, along Idiroko Road in Ota. It was understood that those samples have been stockpiled for more than a year; however, prior to their use the samples were air dried in the laboratory for another two months. This suggested that volumetric expansion in the SSA will have been controlled; in that stockpiling steel slag reduces the concentration of CaO [23]. Subsequently, the chemical composition of the steel slag presented in figure 2, was obtained using standard X-ray fluorescence spectroscopy. The obtained compositions were compared to the findings of [15]. Free CaO and MNO had their concentration falling below the concentration obtained by [15], most likely due to the leaching away of these oxides after adequate stockpiling of the steel slag.

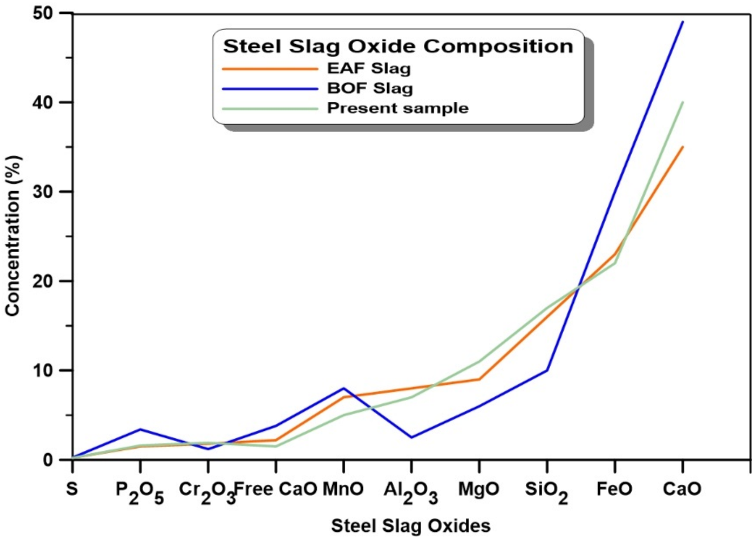


Figure 2: Oxides Composition of the Steel Slag Used

The samples were pulverized and graded into various targeted SSA sizes using the standard BS sieve sizes. However, other materials utilised in this study includes: Ordinary Portland cement, river sand as fine aggregate, and granite crushed stone as coarse aggregate only for the control mixes. The resistance of SSA and NA to impact and gradually applied compressive loads were determined, both aggregate crushing value (ACV) and aggregate impact value (AIV) of the SSA and gravel used were determined in accordance with requirement of [24] and [25] respectively.

Batching, mixing and testing of the concrete samples were performed at the Concrete Laboratory of Department of Civil Engineering, Covenant University, Ota. Concrete mixes in 1:2:4 ratios of cement, sand and SSA or gravel (as the case maybe); batched by weight, and a water cement ratio of 0.6 were considered. More so, workability of the concrete mixes were ascertained by slump tests, which were carried out on the freshly mixed concrete in accordance with the provisions of [26]. A total of 54 (150mm×150mm×150mm) concrete cubes were tested. The cubes comprised of 27 samples each made with SSA, and gravel as coarse aggregate respectively. They were subjected to compression testing in triplicates after 7, 21 and 28 days curing periods by immersion in water tank at $27^{o}$C. Compression test was performed in line with the requirements of [27].

## III.RESULT & DISCUSSION

Prior to the concrete testing, both the SSA and NA were subjected to AIV and ACV tests, the results are presented in Figure 3. The result indicated that SSA are stronger than the NA used for the study, when compared with the BS recommendations. The SSA possess ACV and AIV values which represented about 57 % higher than the NA values. Thus, SSA results are in alignment with the findings of [28], where ACV and AIV are within limits (23 to 30%) and (17 to 21%) respectively. The results obtained from concrete made with SSA were compared to that made with granite as coarse aggregate (that is NA). Figure 4 shows the results obtained from the slump test. For both the concrete made with SSA and NA, it was observed that the slump increases with increasing aggregate sizes. This could be as a result of constant water-cement ratio used in the mixing of the concrete. It was an indication that large size of aggregates increases fluidity or consistency due to low aggregate-cement ratio. More so, the increment in the size of aggregate increases; fluidity, consistency and workability due to the reduction in surface area. It was seen from figure 4 that the slumps for the control mix (NA) with different aggregate sizes are higher than that of the SSA concrete. Concrete made with ¾ inch NA possess highest slump, which represented about 26.7% increment compared to SSA concrete. This variation could be attributed to the resulting effect of the smoothness and roughness of the two aggregates (granite and steel slag) respectively. In fresh concrete, the smoother the coarse aggregates, the more fluid and workable the concrete is. The texture of the steel slag aggregate is rougher than that of that of granite, which is why the slump values for the steel slag concrete were less than that of the normal concrete.

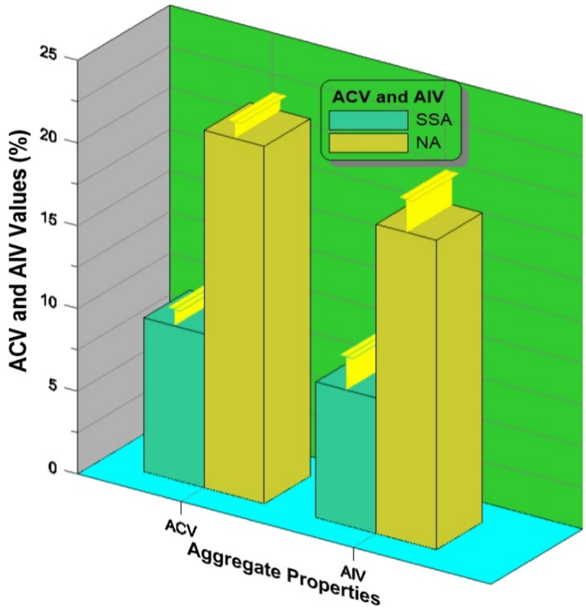


Figure 3: ACV and AIV of the Aggregates Used

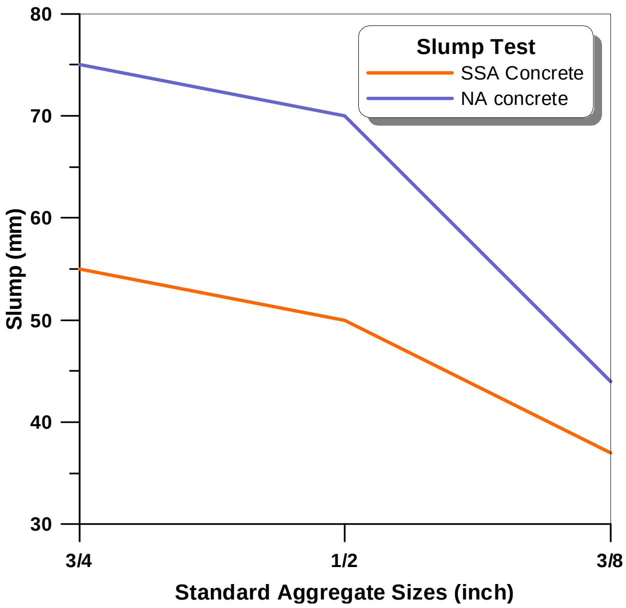


Figure 4: Slump test results

Figures 5, 6 and 7 presents the compressive strength developed per curing period for ½ inch, ¾ and 3/8 inch aggregate concretes respectively.

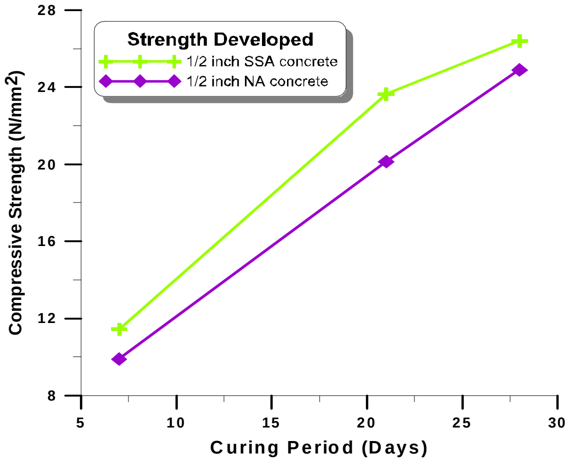


Figure 5: Compressive strength developed for ½ inch aggregate concrete

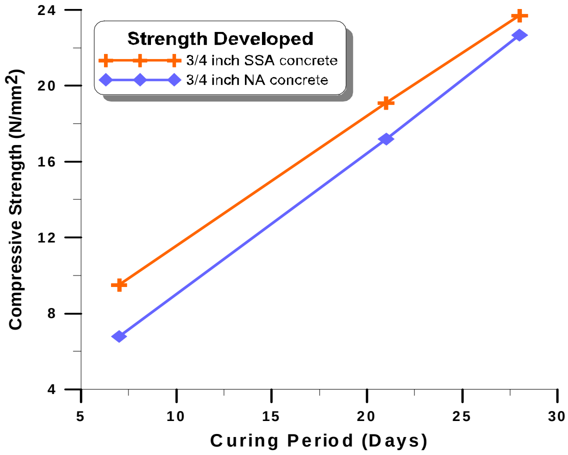


Figure 6: Compressive strength developed for 3/4 inch aggregate concrete

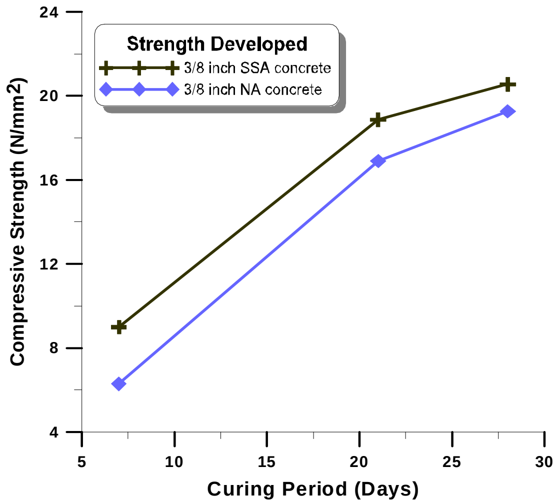


Figure 7: Compressive strength developed for 3/8 inch aggregate concrete

As expected, the compressive strength increased with age in both the SSA and NA concretes, for all the coarse aggregate sizes considered. However, SSA concrete developed an appreciable compressive strength than the NA concrete for all the three aggregate sizes considered. However, ½ inch SSA concrete developed more strength than other samples, with 26.4 N/mm$^2$ developed after the 28 day testing. Moreover, the value is more than the 25 N/mm$^2$ recommended by [29], that concrete strength should not be less than 25 N/mm$^2$. This corresponds to the results obtained by [30], who also conducted compressive strength tests and their results showed that the 28 day strength was increased by 21% with replacement of NA with SSA. Consequently, it was affirmed that steel slag is a suitable material for construction, mostly when high strength are targeted and perhaps when concrete are to be produced in an eco-friendly manner.

On the other hand, compressive strengths obtained for the ¾ inch and 3/8 inch SSA concrete were lesser than the minimum recommended value after 28 days testing. Hence, it is noteworthy to state that SSA produces better result than NA concrete when they are tested under the same condition and specification. Ductility of the concrete [31] was enhanced by the influence of SSA.

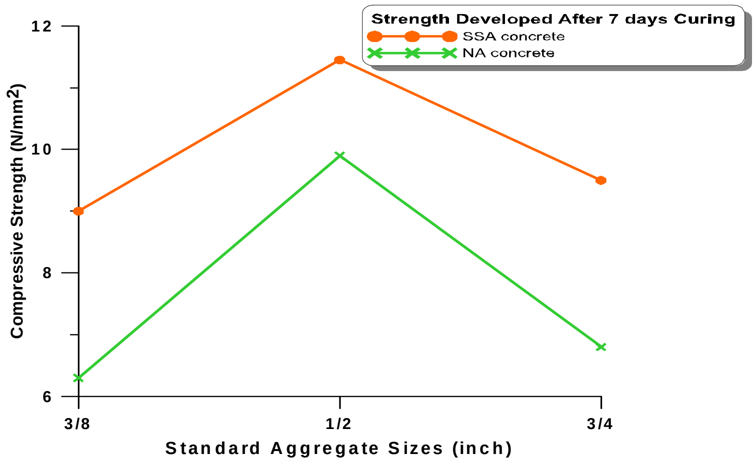


Figure 8: Compressive strength variation with aggregate sizes at 7 day

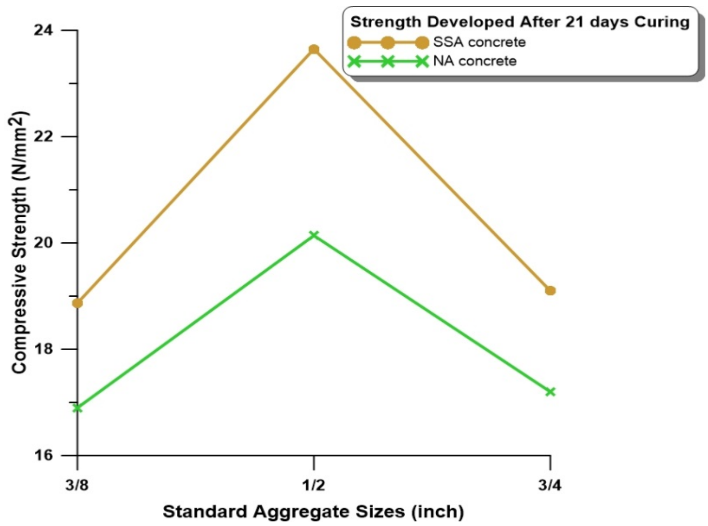


Figure 9: Compressive strength variation with aggregate sizes at 21 day

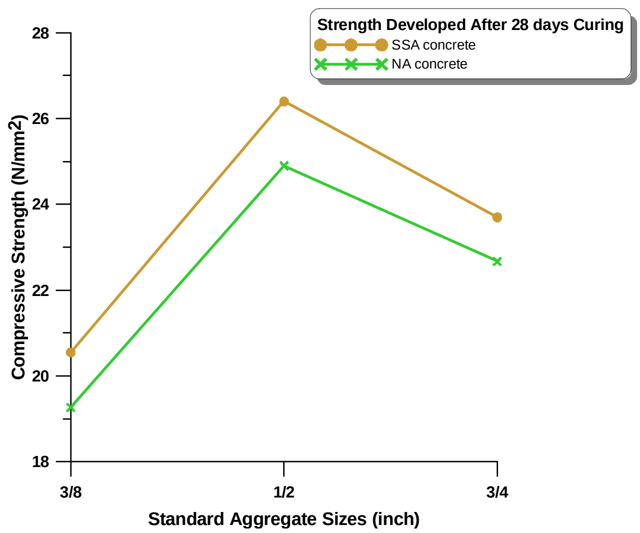


Figure 10: Compressive strength variation with aggregate sizes at 28 day

After establishing the fact that SSA concrete is more durable than the conventional concrete, the next basis of comparison is by the aggregate size variation. From figures 8, 9 and 10, it was observed that the 28-day strength of the ½ inch SSA concrete was the highest of the three aggregate sizes considered. It was followed by the ¾ inch SSA aggregate and least strong of the three sizes tested was that of the 3/8 inch.

## IV. CONCLUSION

This study has explored the influence of EAF SSA sizes on the workability and mechanical properties of concrete. The following conclusions were drawn from the investigation;

i. The quality of coarse aggregate has a significant effect on the compressive strength of high strength concrete. The compressive strength of SSA aggregate concrete was more than that of crushed NA concrete.

ii. The physical and mechanical properties of the SSA are better than that of NA. The ACV and AIV values obtained for SSA are in conformity with the BS codes than the NA. Hence the former can be utilized as an alternative to NA in concrete production.

iii. NA concrete possess good workability than the SSA concrete. This was affirmed from the slump test result, NA gave a 26.7% slump value than the SSA concrete at all considered aggregate sizes.

Finally, it could be deduced that SSA is a best potential material that can be used as an alternative to replace the NA in concrete production. The benefits gained from the use of waste materials include providing the solution to the waste disposal problems of construction and demolition waste, reducing the dependency on natural resources. More so, SSA in concrete constitute a green building construction, which enhances sustainability of the environment.

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