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ASSESSMENT OF STEEL SLAG AS REPLACEMENT FOR COARSE AGGREGATE IN CONCRETE: A REVIEW

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Abstract: This study presents a review on the utilization of steel slag as replacement for coarse aggregate in concrete. Merits and demerits of steel slag in concrete as well as its physical properties and chemical compositions of steel slag are also presented. It has been reported that it is economical to use steel slag, as the costs of steel slag are just about 50% of that of conventional aggregates. However, the optimum replacement of coarse aggregate with steel slag that gives better mechanical properties (compressive strength, tensile strength and flexural strength) than conventional concrete is found to be between 30 and 60%. In South Western part of Nigeria, there are numbers of steel/iron producing company with large deposits of steel slag. 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.

Keywords: steel slag, coarse aggregate, compressive strength, tensile strength, flexural strength

INTRODUCTION

Concrete is one of the most widely used construction material in the world. It can be cast in diverse shapes. Concrete is a composite material formed by the combination of cement, sand, coarse aggregate and water in a particular proportion in such a way that the concrete produced meets the needs as regards its workability, strength, durability and economy (Abdul Kadar and Dhanalakshmi, 2016). The aggregates typically account for about 75% of the concrete volume and play a substantial role in different concrete properties. 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 (Ravikumar *et al.,* 2015). Industrial waste materials such as coal ash, blast furnace slag and steel slag and agricultural waste materials such as coconut shell, palm kernel shell etc. have been used by many researchers in replacement of aggregate in concrete for the purpose of recycling industrial and agricultural waste materials.

Steel slag (SS) is a by-product from steel production. It can be categorized as carbon steel slag and stainless steel slag according to the type of steel, and as pre-treatment slag, basic oxygen furnace slag (BOFS), electrical arc furnace slag (EAFS), ladle refining slag (LFS) and casting residue according to the steelmaking process (Yi *et al.,* 2012). The molten liquid is a complex solution of silicates and oxides that solidifies on cooling and forms steel slag. However, 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). Use of more and more environmentally 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).

Utilization of steel slag is economical because the costs of steel slag are just about 50% of that of conventional aggregates (Tiwari *et al.*, 2016). It does not contain materials such as chlorides, organic impurities, clay and shells (Tarawneh *et al.*, 2014). It leads to increased strength as materials age (Tarawneh *et al.*, 2014). According to Abrol *et al.* (2016), steel slag has longer life span and durability than the natural aggregates, and when used in asphalt layer in the laying of roads, steel slag offers a better non-skid-able surface (Tarawneh *et al.*, 2014). The use of slag promotes the conservation of natural resources (Kothai and Malathy, 2014). The disadvantage of steel slag is that it will lead to social and environmental problem if not properly disposed (Kumar and Kumar, 2016). However, Palod *et al.* (2017) reported that steel slag possess high mineralogical composition and has higher density than other binders.

Several studies proved that the use of steel slag in concrete as aggregate improves its mechanical and durability properties (Sekaran *et al.*, 2015). Subramani and Ravi (2015), also reported that when steel slag is used in concrete, it acts as filler and as a strengthening material. According to Sezer and Gulderen (2015), its high density makes its use advantageous in some constructions such as foundations, retaining walls, breakwater blocks, noise barriers, radiation insulators etc. Tran *et al.* (2014) also noted that steel slag aggregates improve the compressive strength, tensile strength, flexural strength and modulus of elasticity of concrete.

In Nigeria and many countries of the world, steel is mainly produced from smelting of metal scrap metals and hundreds of tonnes of steel slag are produced every year. And most often, steel slag are disposed around the steel producing centres posing environmental threats. However, not much research work has been reported on the use of steel slag produced from scrap metals, as produced in Nigeria (Olonade *et al.*, 2015).

PHYSICAL PROPERTIES OF STEEL SLAG AND GRANITE

Some selected physical properties of steel slag and coarse aggregate (granite); Specific Gravity, Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV) and Los Angeles Abrasion Value (LAAV) from some previous research work are presented in Table 1.

Table 1: Physical Properties of Steel Slag and Granite

Source	Aggregate Type	Specific Gravity	AIV (%)	ACV (%)	LAAV (%)
Priya et al. (2017)	Steel Slag Granite	2.97 2.93	40 28.9	21.73 12.4	23.7 13.4
Yi (2008)	Steel Slag Granite	- -	17.2 20.54	26.05 26.10	9.80 9.80
Abrol et al. (2016)	Steel Slag Granite	3.2-3.6 -	- -	- -	- -
Sekaran et al., (2015)	Steel Slag Granite	2.9 2.75	24.93 28	19.25 26	16.4 18.6
Khafaga et al. (2014)	Steel Slag Granite	3.48 2.65	6.6 10.00	11.4 22.00	13.5 18.50
Olonade et al. (2015)	Steel Slag Granite	2.63 2.71	- -	- -	- -
Warudkar & Nigade (2015)	Steel Slag Granite	2.61 2.673	- -	- -	- -
Tran et al. (2014)	Steel Slag Granite	- -	- -	16.83 13.65	6.03 4.24
Tarawneh et al. (2014)	Steel Slag Granite	- -	6.31 23.13	- -	20.26 23.06
Kothai and Malathy (2014)	Steel Slag Granite	2.95 2.75	- -	- -	- -

As observed from Table 1, steel slag possesses higher specific gravity value than coarse aggregate (Priya *et al.*, 2017; Sekaran *et al.*, 2015; Khafaga *et al.*, 2014 and Kothai and Malathy, 2014) but the value of specific gravity reported by Olonade *et al.*, (2015) and Warudkar & Nigade (2015) have lower specific gravity compare to coarse aggregate. Although, these values are relatively close implying that steel slag can perform as substitutes for coarse aggregates. The Aggregate Impact Value (AIV) indicates that coarse aggregate possesses higher values than steel slag except from that of Priya *et al.*, (2017). Similarly, the Aggregate Crushing Value (ACV) possesses similar properties except from the one reported by Priya *et al.*, (2017), Sekaran *et al.*, (2015) and Khafaga *et al.*, (2014). Nonetheless, Los Angeles Abrasion Value (LAAV) also indicates that steel slag possesses similar properties to coarse aggregate except from those reported by Priya *et al.*, (2017) and Khafaga *et al.*, (2014). This shows that steel slag has relatively similar physical properties to coarse aggregates, which is an indication that slag can relatively perform as substitutes for coarse aggregates in concrete production. This will thereby reduce the environmental pollution caused by the heaps of steel slag, improve the properties of concrete and minimize the cost of concrete production.

Chemical composition of steel slag

Both Basic-Oxygen- Furnace (BOF) and Electric-Arc-Furnace (EAF) slag are formed during basic steelmaking operations, as explained above. Therefore, in general, the chemical and mineralogical compositions of BOF and EAF slag are similar. Calcium oxide and iron oxide are the two major chemical constituents of both EAF and BOF slag. Ladle slag is generated during the steel refining processes in which several alloys are added to the ladle furnace to produce different grades of steel. For this reason, the chemical constituents of ladle slag differ from those of BOF and EAF slag (Yildirim and Prezzi, 2011). However, chemical compositions of steel slag from previous research work are provided in Table 2.

Table 2: Chemical Compositions of Steel Slag

Source	SIO2	Al2O3	Fe2O3	CaO	MgO	K2O	MnO	TiO2	P2O5
Sezer and Gulderen (2015)	17.79	7.82	35.22	24.62	-	-	-	-	-
Abrol et al., (2016)	10-19	1-3	-	40-52	-	-	5-8	-	0.5-1
Khafaga et al. (2014)	13.10	5.510	36.80	33.0	5.030	-	4.180	-	0.598
Gokul et al., (2012)	12.5	2.4	31.2	41.3	4.3	-	6.1	0.8	1.1
Olonade et al., (2015)	42.40	15.00	31.90	5.00	-	2.05	-	-	-
Tran et al., (2014)	16.3	6.07	39.2	28.9	1.68	-	4.02	1.02	0.36
Tarawneh et al., (2014)	9-11	1.4-0.7	10-13	50-57	1-2	0.04-0.01	4-5	-	3.2-2.3
Kothai and Malathy (2013)	10-19	1-3	20-30	40-52	5-10	-	5-8	-	0.5-1
Kothai and Malathy (2014)	10-19	1-3	20-30	40-52	5-10	-	5-8	-	0.5-1
Subramani and Ravi (2015)	10-19	1-3	10-40	40-52	5-10	-	5-8	-	-

The steel slag chemical compositions results of Khafaga *et al.*, (2014) and Gokul *et al.*, (2012) falls within the acceptable limits reported by Abrol *et al.*, (2016), Kothai and Malathy (2013), Kothai and Malathy (2014) and Subramani and Ravi (2015) as contain in Table 2. It is observed from the Table that SiO_2, Fe_2O_3 CaO and MgO are the major constituents of steel slag.

EFFECT OF STEEL SLAG ON THE PROPERTIES OF CONCRETE

— Compressive Strength

Khafaga *et al.* (2014) investigated twenty-four normal, high and ultra-high strength concrete mixtures with replacement percentages 0, 33.33, 66.67 and 100% by weight of the coarse aggregate with two cement contents (450 and 600 kg/m^3) and three silica fume percentages (0, 10 and 20%). Their results indicated that the optimum concrete compressive strength was obtained for the mixtures with a percentage of 66.67% steel slag aggregates as a replacement of the coarse aggregate. Qurishee *et al.* (2016) in their experimental study on the use of slag as coarse aggregate and its effect on mechanical properties of concrete. It was reported that compressive strength of concrete made by replacing coarse aggregate with slag is higher than normal conventional concrete. However, the compressive strength for concrete made with partial replacement of coarse aggregate by slag is observed to increase up to replacement level of 40% but decreases afterwards. Kothai and Malathy (2013) in their study concluded that workability of concrete containing steel slag does not have any major change while the compressive strength of different mixes shows reasonable improvement of about 10%.

Gokul *et al.* (2012) investigated the use of mild steel slag as a potential replacement for concrete aggregate. It was concluded from the study that compressive strength and the other tests showed that mild steel slag is superior to the natural aggregates (Figure 1). As observed from the Figure, the 28 days result shows compressive strength increase of the concrete from 0 to 60% replacement of coarse aggregate with steel slag, but later reduced with 80% steel slag in both mixes but increase at 100% replacement of coarse aggregate.

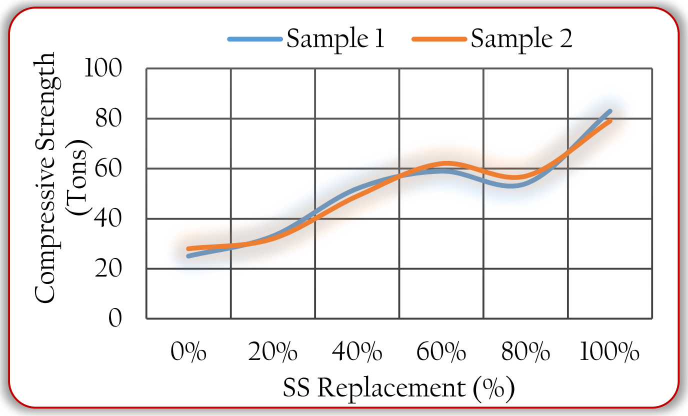

Figure 1: Effect of Steel Slag on the Compressive Strength at 28 day curing (Gokul *et al.*, 2012)

Kumar and Kumar (2016) replaced coarse aggregate with 25, 30 and 35% steel slag and 1% of polypropylene fibre. Results as presented in Figure 2 showed an increase in compressive strength with increasing steel slag, with the partial replacement of coarse aggregate with iron slag containing 35% steel slag and 1% of polypropylene fibre exhibited the highest strength. The results of all the replacements were higher than that conventional concrete. This is an indication that steel slag is good substitute for coarse aggregate in concrete.

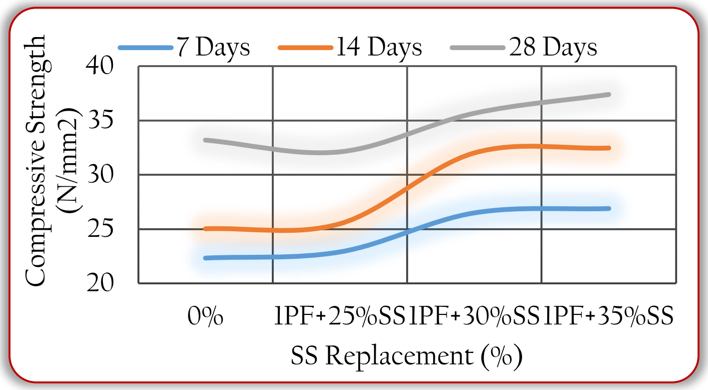

Figure 2: Compressive Strength of Concrete Grade 30 (Kumar and Kumar, 2016)

Raza *et al.* (2014) investigated the strength analysis of concrete by using iron slag as a partial replacement for coarse aggregate in concrete. In this study, coarse aggregate (CA) were partially replaced with iron slag aggregate (ISA) at different proportions of 0, 10, 20, 30, 40 and 50%. The result (Figure 3) shows that 30% replacement of coarse aggregate with iron slag aggregate gives optimum compressive strength.

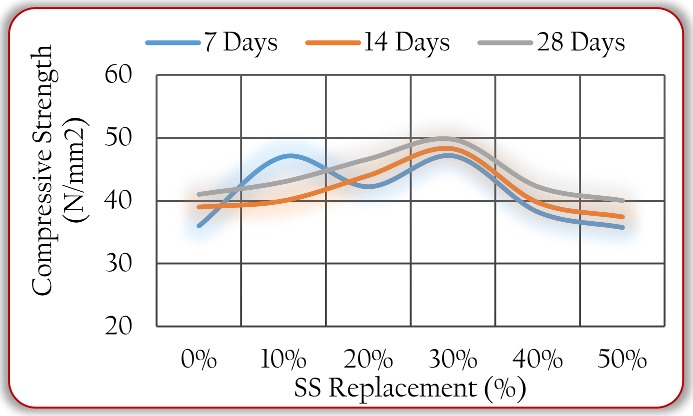

Figure 3: Steel Slag Compressive Strength (Raza *et al.*, 2014)

The research conducted by Thangaselvi (2015) as seen in Figure 4 shows that the compressive strength of concrete increases up to 60% (with an increment of 9.70%) replacement of coarse aggregate with steel slag but the strength decrease at 80% replacement. This is quite in agreement with the previous study conducted by Gokul *et al.* (2012).

Subramani and Ravi (2015) studied the replacement of coarse aggregate with steel slag in concrete and concluded that coarse aggregate replacement level with 60% steel slag in concrete was found to be the optimum level to obtain higher value of strength and durability at 28days of curing (Figure 5).

This shows that the maximum slag replacement to enjoy optimum compressive strength of the concrete is 60%, this is also similar to the findings of the previous studies (Gokul *et al.*, 2012 and Thangaselvi, 2015).

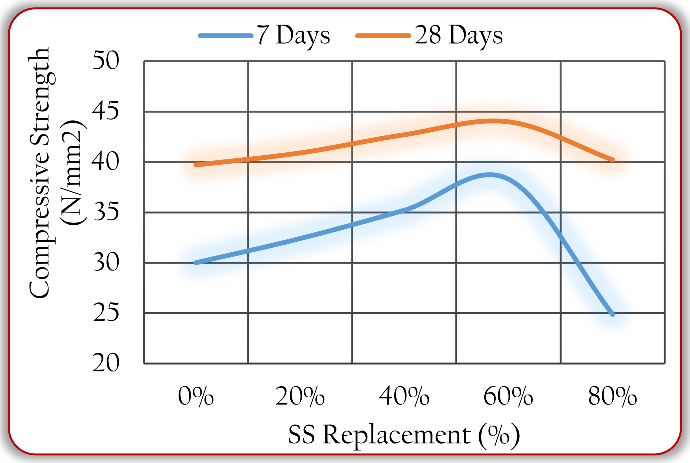

Figure 4: Compressive Strength of Steel Slag Concrete (Thangaselvi, 2015)

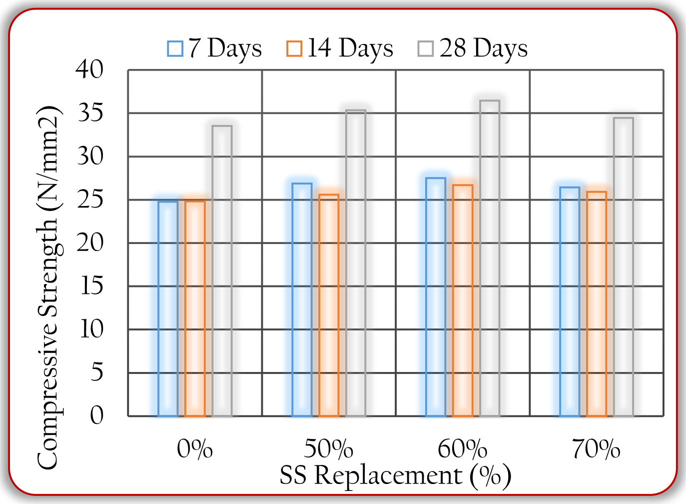

Figure 5: Compressive Strength Vs Steel Slag Concrete (Subramani and Ravi, 2015)

Awoyera *et al.* (2015) examined influence of electric arc furnace (EAF) slag aggregate sizes (as alternative) on the workability and durability of concrete. The study utilised steel slag aggregate (SSA) and natural aggregate (NA) of size 9.54, 12.7 and 19.05 mm. For all the aggregate sizes considered in the research, SSA produced an appreciable compressive strength at 28 days than the NA concrete. However, the NA concrete possesses good workability than the SSA concrete.

Warudkar and Nigade (2015) assessed the performance of partial replacement of coarse aggregate with steel slag in concrete. The study concluded that compressive strength of concrete of all mix increases up to 75% steel slag but decrease with further addition of the replacement. However, the compressive strength (Figure 6) witness 14% increment with 75% of steel slag as partial replacement of coarse aggregate. The improvement in strength might be due to shape, size and surface texture of steel slag aggregates, which provide better bonding between the particles and cement paste.

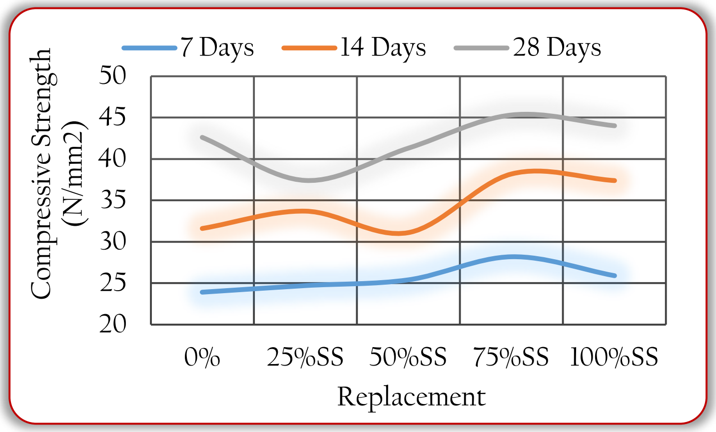

Figure 6: Compressive Strength of Concrete (Warudkar and Nigade, 2015)

Tran *et al.* (2014) investigated the properties of high strength concrete using steel slag coarse aggregate. The steel slag was used to replace 100% coarse aggregates in high strength concrete with varying compressive strengths (60, 70 and 80MPa). The results showed that the strength of the concrete using steel slag aggregate as alternative to coarse aggregate was equivalent to that of conventional concrete. Mohammed *et al.* (2016) also utilized steel slag in concrete as coarse aggregate. The steel slag aggregate was separated into lightweight (SL), heavyweight (SH), and mixed (SM) slag aggregates after collection of the slag from a local steel manufacturing company. It was noted that the compressive strength of concrete made with mixed slag aggregate is similar/better than that of concrete made with brick aggregate while concrete made with heavyweight slag aggregate gives more compressive strength than other aggregates.

Sharma *et al.* (2015) examined the effects of steel slag on concrete. From the results, it was observed that as the percentage of steel slag increases (from 0% to 50%), the strength of concrete increases but decreases at 75% and 100% replacement. The optimum compressive strength was gained at 50% replacement. Ravikumar *et al.* (2015) equally investigated the replacement of steel slag as coarse aggregate in concrete. In this 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 and coarse aggregate replacement with steel slag was 30, 60 and 100%. The result of this study revealed an increment in compressive strength by 4 to 6% for all the grades of concrete, and concluded that steel slag could be use up to 60% replacement in concrete with grade M20, M30, M40 and M50.

Recently, Anifowose *et al.* (2017) examined the density, workability and compressive strength assessment of steel slag in 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 with respect to curing age). They however concluded that steel slag (SS) can successfully be use as a partial replacement of coarse aggregate (crushed stone) in concrete for concrete grade M20 since the strength of concrete with 10, 20, 30, 40 and 50% is higher than the control mix (Figure 7).

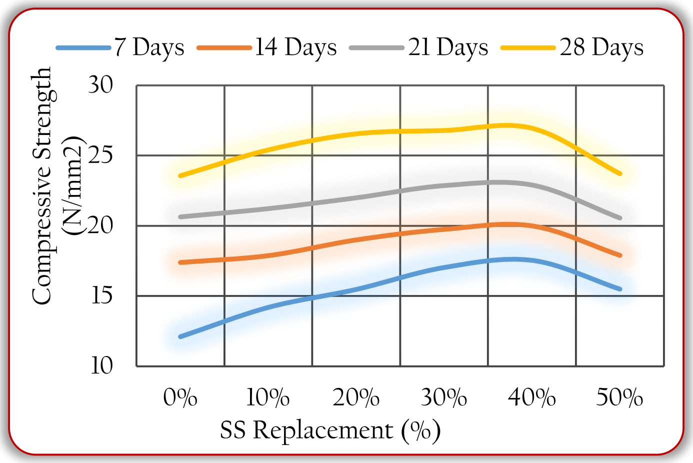

Figure 7: Graphical representation of Compressive Strength against SS Replacement (Anifowose *et al.*, 2017)

— Split tensile strength

Khafaga *et al.* (2014) reported that the optimum split tensile strength was obtained for the mixtures with a percentage of 66.67% steel slag aggregates as a replacement of the coarse aggregate. Qurishee *et al.* (2016) also concluded that concrete with 40% replacement of coarse aggregate with steel slag may offer more tensile strength. However, the results of the study conducted by Kothai and Malathy (2013) showed that split tensile strength for steel slag aggregate concrete was similar to that conventional concrete.

Similar to the findings from Qurishee *et al.* (2016), Study by Kumar and Kumar (2016) also showed that between 30 and 35% of slag by weight of coarse aggregate gave 6% increment in split tensile strength compared to that of the conventional concrete (Figure 8). It is clearly seen from these results that steel slag can be used as an alternative material to coarse aggregates in concrete production.

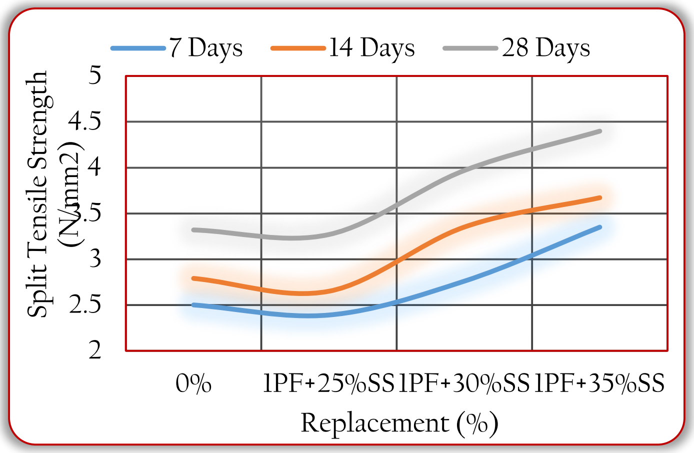

Figure 8: Split Tensile Strength for Concrete Grade 30 (Kumar and Kumar 2016)

Thangaselvi (2015) examined the strength and durability of concrete using steel slag as a partial replacement of coarse aggregate in concrete. The results showed that the optimum split tensile strength of steel slag concrete was found at 60% replacement of coarse aggregate with steel slag (Figure 9).

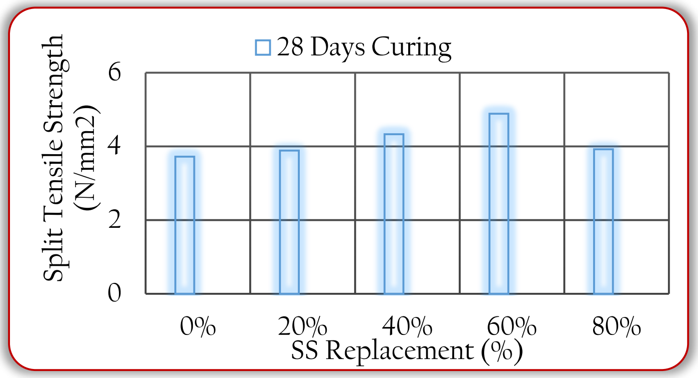

Figure 9: Split Tensile Strength of Steel Slag Concrete (Thangaselvi, 2015)

Subramani and Ravi (2015) conducted study on the partial replacement of coarse aggregate with varying proportions of steel slag (0, 50, 60 and 70%). The results presented in Figure 10 indicated an increase in compressive strength with increasing amount of the steel slag from 0 to 60%, but the strength decreased with further increment of steel slag. It was concluded that the optimum replacement level of coarse aggregate with steel slag that produced the highest tensile strength is 60%. This is an indication that steel slag can be sustainably used to improve the strength of concrete while minimizing the environmental pollution caused by the heaps of steel slag generated by steel manufacturing companies.

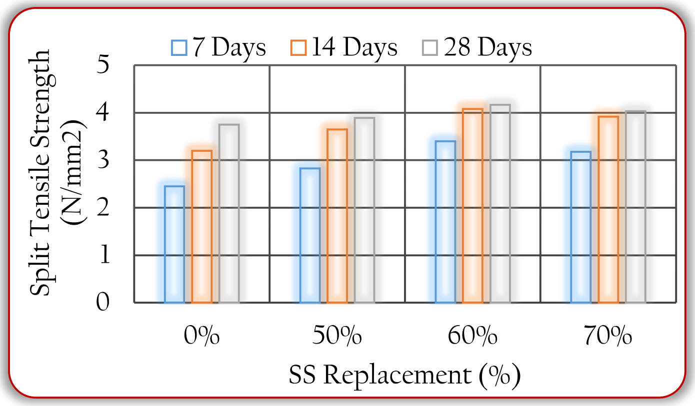

Figure 10: Split Tensile Strength against Steel Slag Concrete (Subramani and Ravi 2015)

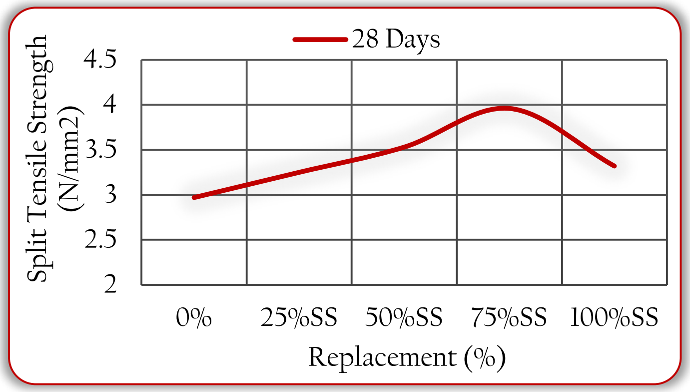

Figure 11: Split Tensile Strength of Concrete at 28 Days Curing (Warudkar and Nigade, 2015)

Warudkar and Nigade (2015) also examined the split tensile strength of steel slag-granite concrete at 28th day. The result showed that there is increment in strength from 0 to 75% (Figure 11) replacement of steel slag but decreased at 100%. Sharma *et al.* (2015) concluded that the maximum split tensile strength was obtained at 50% replacement of coarse aggregate with steel slag. After 50% replacement of coarse aggregate with steel slag, slight decrease in concrete strength was observed. Ravikumar *et al.*, (2015) reported that split tensile strength increases as the percentage of coarse aggregate replacement with steel slag increased in M20 and M40 grade and decrease at 100% replacement, whereas in M30 and M50 grade the strength decreases at 30% and increases at 60% then decreases at 100%. This trend is also similar to the findings of the previous study (Subramani and Ravi, 2015)

— Flexural strength

Khafaga *et al.* (2014) carried out study to investigate the effect of partial replacement of coarse aggregate with steel slag and showed that the optimum concrete flexural strength was obtained at 66.67% replacement of the coarse aggregate with steel slag. Kumar and Kumar (2016) also reported that 30 and 35% of slag by weight of coarse aggregate in concrete witnessed 6% increment in flexural strength compared to conventional concrete (Figure 12).

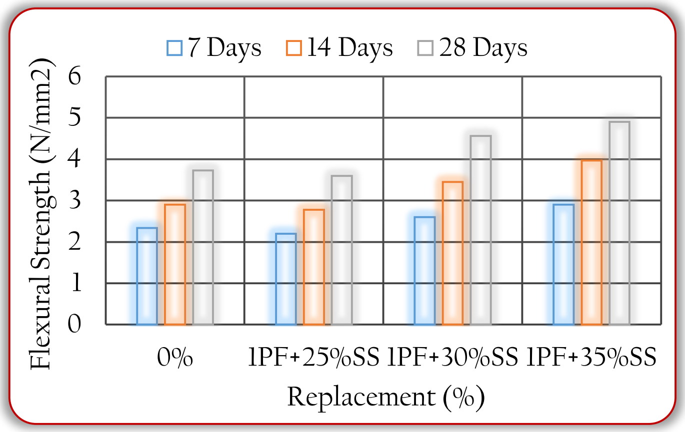

Figure 12: Flexural Strength of Concrete (Kumar and Kumar, 2016)

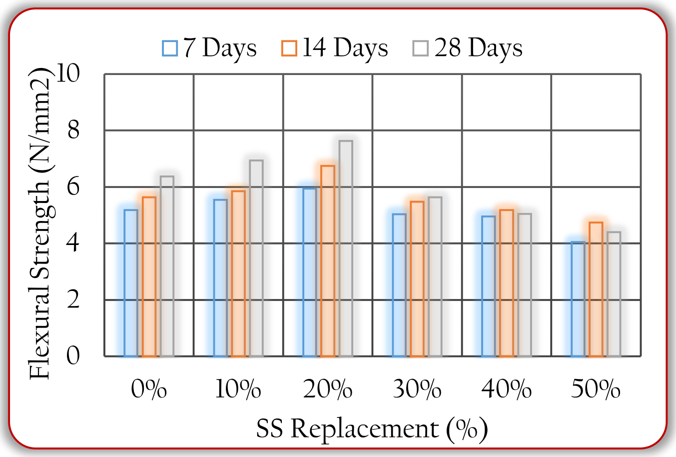

Figure 13: Flexural Strength of Steel Slag Concrete (Raza *et al.*, 2014)

Raza *et al.* (2014) conducted a study to examine the influence of steel slag on the properties of steel slag-concrete and concluded that the flexural strength of concrete with 20% steel slag is more than that of the conventional concrete (Figure 13).

Figure 14 shows the effect of steel slag addition on the flexural strength of concrete. From this study, Thangaselvi (2015) concluded that the maximum flexural strength was obtained at 60% replacement of natural aggregate by steel slag with an increment of 18.20% compared with conventional concrete. This finding is also similar to that of the previous study conducted by Khafaga *et al.* (2014).

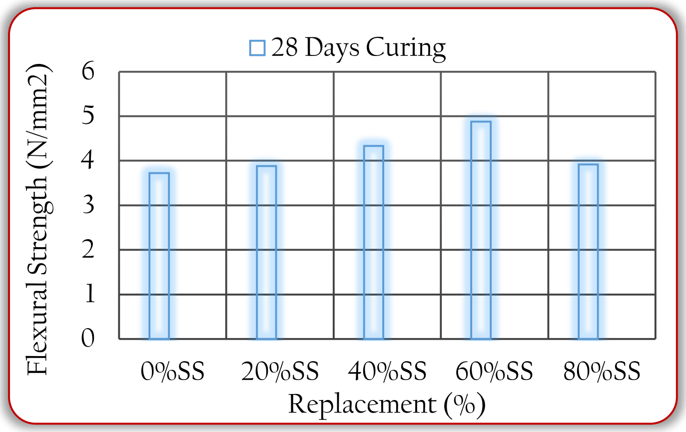

Figure 14: Effect on Flexural Strength of Steel Slag (Thangaselvi 2015)

Subramani and Ravi (2015) investigated the replacement of coarse aggregate with steel slag in concrete (Figure 15). Their results showed that concrete with 60% steel slag has the highest flexural strength at 28days of curing, which is in line with the earlier studies reported by Khafaga *et al.* (2014) and Thangaselvi (2015).

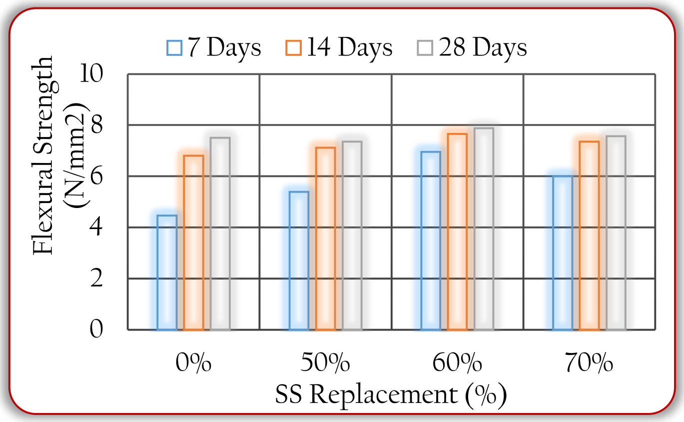

Figure 15: Flexural Strength Vs Steel Slag Concrete (Subramani and Ravi 2015)

Results of the research shown in Figure 16, which was conducted by Warudkar and Nigade (2015) showed that the flexural strength of concrete using steel slag at 28th day increased with steel slag up to 75% replacement level but decreased with further increment of steel slag.

Sharma *et al.* (2015) also studied the beneficial effects of steel slag on concrete and observed that the optimum replacement of coarse aggregate with steel slag that produced the highest flexural strength was found at 50% replacement. Ravikumar *et al.* (2015) concluded that 60% replacement of coarse aggregate with steel slag could be used in concrete grade M20, M30, M40 and M50 while full replacement by steel slag decreased the strength considerably.

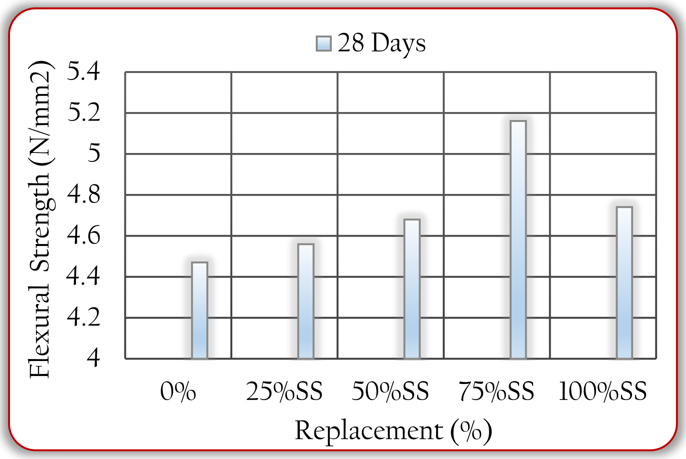

Figure 16: Flexural Strength of Concrete Using Steel Slag (Warudkar and Nigade, 2015)

CONCLUSIONS

Based on the extensive reviews of the previous studies carried out to investigate the effects of partial replacement of coarse aggregate with steel slag, the following conclusions have been drawn:

- From chemical properties, it was observed that SiO_2, Fe_2O_3 CaO and MgO are the major constituents of steel slag.
- Steel slag possesses higher value of specific gravity and Aggregate Impact Value (AIV) than coarse aggregate but have similar values of the Aggregate Crushing Value (ACV) and Los Angeles Abrasion Value (LAAV) with coarse aggregate. This therefore makes steel slag a suitable substitute for coarse aggregate in concrete production.
- The optimum replacement of coarse aggregate with steel slag that gives higher compressive strength than conventional concrete is found to be between the range of 30 and 60%.
- 40 to 60% steel slag (by weight of coarse aggregate) in concrete will produce an improved split tensile strength compared to conventional concrete.
- The optimum replacement of coarse aggregate with steel slag in concrete that gives enhanced flexural strength is between 20 to 60%.
- Tiwari *et al.*, (2016) reported that it is economical to use steel slag to improve the strength characteristics of concrete, as the costs of steel slag are just about 50% of that of conventional aggregates.
- Only few researchers have used different water to cement ratio and different concrete grades in steel slag-concrete production.
- In South Western part of Nigeria, there are numbers of steel/iron producing company with large deposit of steel slag. Therefore, there is need for the utilization of this by-product (steel slag) in concrete production in Nigeria as the cost of natural aggregates (fine and coarse aggregate) is becoming higher.

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