STRUCTURAL ASSESSMENT OF FOAMED CONCRETE CONTAINING STEEL SLAG AS PARTIAL REPLACEMENT OF SAND

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ABSTRACT
In this study, the potential of foamed concrete, in which river dredged sand is replaced with pulverized steel slag, as structural material was investigated. The variables are: pulverized steel slag content (0%, 10%, 20%, 30%, 40% and 50%), curing methods (air and water) and curing ages (7, 14, 21 and 28 days). Total of one and forty four (144) 150mm cube specimens were used for the determination of both the compressive strength and the density of the foamed concrete at the testing days. The results show that 30% steel slag replacement level gave a maximum of 20.3% increase in compressive strength at 28^{th} day for air-cured cube specimens. Generally, the air-cured specimens showed higher compressive strength than water cured specimens at all ages.

Keywords: Foamed Concrete, Steel Slag, Compressive Strength, Curing Method

INTRODUCTION

EBS-Associate (2001) defined foamed concrete as lightweight concrete which comprises fine aggregate, cement, water and large amount of dispersed air pores in the mortar matrix. Fine aggregate is a major component of foamed concrete. The fine aggregate used in foamed concrete production contributes to the structural and non-structural properties of the foamed concrete. Jones *et al.* (2005) observed that diverse types of fine aggregate can be used in foamed concrete production. They concluded that foamed concrete production has the potential of utilizing industrial waste such as incinerator bottom ash recycle glass, Rubber tyres (crumbs), foundry sand and china clay as raw materials. In developing countries, these industrial wastes are becoming a health and environmental problem especially where technology for efficient waste disposal is lacking.

Research findings (Falade *et al.*, 2013; Jones and McCarthy 2005; Pan *et al.*, 2006) have shown that some industrial and agricultural waste can be used as partial replacement of cement or fine aggregate in foamed concrete production. Falade *et al.* (2013) investigated the effect of partial replacement of cement with pulverized cow bone on the structural properties of foamed concrete. They concluded that up to 20% of the cement component of foamed concrete can be replaced with pulverized cow bone for foamed concrete production without losing its classification as lightweight structural concrete according to RILEM standard and without significant difference when compared with 28-day compressive strength of specimens without pulverized bone. Jones and McCarthy (2005) examined the potential of foamed concrete as a structural material; using fine fly ash, coarse fly ash as fine aggregates. They observed reduction in shrinkage strain; improved compressive strength and improved modulus of Elasticity. Pan *et al.* (2006) investigated preparation of high performance foamed concrete; using ultra- granulated blast-furnace slag, pulverized fly ash, condensed silica fume as replacement of fine aggregate. They concluded that the foamed concrete made with these materials developed an improved compressive strength up to 44.1N/mm^2 for oven dried specimens at 28-day; improved workability (excellent flow-ability) and low thermal insulation capacity. Kunhanadan and Ramamurty (2006) investigated the effect of using fly ash as fine aggregate on the properties of foamed concrete. They observed that the plastic density of foamed concrete depends on the type of the fine aggregate; particle size distribution (fine aggregate). They also observed that foamed concrete that contains varying proportions of fly ash developed higher compressive strength when compared to foamed concrete that does not contain fly ash. Kearsley (1996, 1999); Falade *et al.* (2011) agreed that water cured foamed concrete has lower compressive strength compared to other foamed concrete specimens cured in other media: sealed curing; air curing at different temperatures; moist curing; steam curing at atmospheric pressure and high pressure steam curing (also called autoclaving).

The aim of this work is to investigate the feasibility of replacing fine aggregate with steel slag in foamed concrete. Jones *et al.* (2005) had earlier suggested that diverse types of fine aggregate can be used in foamed concrete production. Steel slag is a waste material obtained during steel production in a process that utilizes recycled waste steel products as raw material. It was learnt from the steel company (Universal Steel Company, Ikeja, Lagos) visited that the steel slag was only used for filling of failed portions of earth road. The potential of pulverized steel slag as fine aggregate in foamed concrete would provide an economic means of utilizing steel slag in the construction industry.

EXPERIMENTAL PROCEDURES

Materials

Ordinary Portland cement whose properties conform to BS EN 197-1:2011 was used as the main binder. The steel slag was obtained from Universal Steel Company, Ikeja, Lagos. This company uses scraps as its raw material for steel production (Utilization of solid waste). The slag is a by-product of the steel production process. The steel slag was crushed and pulverized into fine aggregate at Federal Institute for Industrial Research Oshodi (FIIRO), Lagos. The pulverized steel slag was packaged in bags and kept in cool and dry place in the laboratory. River sand was used for this work. Sieve analysis of the sand and steel slag was carried out. Only particles passing through sieve size 2.00mm but retained on sieve size 0.150mm aperture in accordance with BS EN 12620:2013 were used. British Cement Association (BCA) (1994) recommends that the maximum fine aggregate size for foamed concrete production should be 2.0mm with 60-90% of it passing through 600 micron sieve. Finer aggregate sizes are recommended because the weight of coarse aggregate might be more than the foam can suspend; which leads to collapse of the foam during mixing. Maziah (2011) observed that finer aggregate sizes help to improve the foamed concrete flow characteristics and stability. The water used is free of any form of impurities. This is important, especially with the use of enzyme based foaming agent because organic contamination can have an adverse effect on the quality of the foam, and hence on the concrete produced. Enzyme based foaming agent SL200 was used for the production of the required foam. Lucas (2008) reported that one kilogram of SL200 produces average of 275-350 litres of foam.

Mix Design

Trial mix design to establish the appropriate combination of various materials to achieve the desired plastic density of 1750kg/m^3 at 28th day was developed. Kearsly and Mostert (2005); Joe (2003) agreed that the general rules regarding water/cement ratio (w/c), free water content and maintaining a unit volume applies in foamed concrete design as in normal weight concrete design. In foamed concrete design, the specified target plastic density is the prime design criterion, rather than the compressive strength. The design equations are as follows:

f_{cu} z f (W/C, D_o, C) (1)

$D = f(F_m)$ (2)

Where;

f_{cu} - Compressive strength, W/C - water/cement ratio, D_o- Dry density, C- Cement quantity

D- Plastic density of the mix and F_m- Foam quantity.

$D = C + W + F$ (3)

Where;

W- Water quantity, F - Fine aggregate quantity.

$W = (W/C) \times C$ (4)

$D = D_0 + 150$ Brady *et al.* (2001) (5)

D_0-Specified dry density (kg/m^3) at 28-day =1,600 kg/m^3 (structural foamed concrete)

C = 350 kg/m^3 Jones (2000); W/C = 0.7 kg/m^3 (base mix). Substituting these values into Equations 3, 4 and 5 the values of other parameters were derived. W = 250 kg/m^3; F= 1150 kg/m^3. Mix constituent proportions per cubic metre for the foam concrete mixes is presented in Table 1. The specific densities of the sand and steel slag are 2.66 and 3.47 respectively, thus the effect of difference in specific densities of sand and steel slag in the volume of aggregate at varying proportions of steel slag is shown in Table 1. The properties of foamed concrete measured are the hardened density and compressive strength. Three 150mm cubes from each mix at the testing day were used for measuring the characteristics

Table1: Mix constituent proportions for the foamed concrete mixes (per cubic metre)

Steel Slag Replacement %	Cement (kg)	Fine Aggregate (kg)		Volume of aggregates (m^3)	% reduction in Volume
		Sand	Steel slag		
0	350	1150	0	0.43	Control
10	350	1035	115	0.42	2.33
20	350	920	230	0.41	4.65
30	350	805	345	0.40	6.97
40	350	690	460	0.39	9.30
50	350	575	575	0.38	11.63

Compressive Strength Test: Compressive strength was measured at 7, 14, 21, 28 days in conformity to BS EN 12390-3:2009. The water-cured specimens were tested immediately after removal from the curing tank to determine the effect of pore water on the compressive strength of foamed concrete. The strength of each cube was determined using 600 kN Avery Denison Universal Testing Machine, at a loading rate of 120 kN/min. Three specimens were tested for each of the curing age.

RESULTS AND DISCUSSION

Composition of Steel Slag

The chemical composition of steel slag is presented in Table 2. Aiban and Al-abdul (1997) reported the standard composition of steel slag. The chemical composition of the steel slag obtained from Universal Steel Company was determined in the Chemistry Department of University of Lagos.

Table 2: Composition of steel slag (by mass)

Elements	Standard Composition	Steel Slag Composition
Lime (CAO)	20-40%	37.52%
Silica (SiO_2)	10-20%	33.24%
Alumina (Al_2O_3)	5-10%	9.4%
Magnesia (MgO)	7-12%	13.24%
Iron Oxide (FeO)	3-13%	2.5%
Magnesium (MnO)	2-4%	1.5%
Sulphur (S)	Not provided	2.6%

Penttala (2009) reported that aggregate whose chemical composition contains some chemical compounds (Cl^-, SO_4^{2-} Na_2O and K_2O) will lead to deterioration of concrete; when it is use in concrete production. Table 2 shows that the chemical composition of the steel slag does not contain any of the compounds that will lead to the deterioration of the foamed concrete.

Effect of Varying Proportions of Steel Slag On:

Density

The results of variation of concrete densities with different steel slag contents at different curing ages and curing methods are shown in Table 3. The average densities of the cubes increased mildly with increase in steel slag content up to 30%. A decline in density was observed in 40 and 50% steel slag replacement. These trends may be attributed to the fact that above 30% steel slag replacement levels, there were reductions in volume of the fine aggregate up to 9.3% and 11.6% respectively (Table 1). Consequently, there was reduction in the surface area of fine aggregates; this led to increase in the workability of the base mix. It was observed that the volume of foamed concrete produced increased leading to reduction in density. For example, at 28th day, air-cured samples have densities of 1243, 1244, 1252 1302, 1260 and 1211kg/m³ for 0, 10, 20, 30, 40 and 50% respectively. The same trend was also observed at other curing ages of 7, 14 and 21 days.

Table 3: Effect of steel slag content on density and Compressive Strength of foamed

% of Steel Slag	Curing Age (Days)	Density (kg/m^3)		Compressive Strength (N/mm^2)	
		Air-cured	Water-cured	Air-cured	Water-cured
0	7	1267	1309	3.077	2.963
	14	1251	1325	3.185	3.259
	21	1244	1326	3.481	3.556
	28	1243	1328	3.630	3.185
10	7	1280	1323	3.259	2.963
	14	1257	1334	3.481	3.333
	21	1255	1353	3.555	3.407
	28	1244	1379	3.778	3.259
20	7	1300	1338	3.333	3.037
	14	1261	1345	3.556	3.407
	21	1259	1358	3.630	3.407
	28	1252	1368	3.850	3.259
30	7	1314	1348	3.407	3.630
	14	1304	1378	3.704	3.704
	21	1304	1392	4.148	3.889
	28	1302	1422	4.370	3.778
40	7	1275	1333	2.222	2.074
	14	1267	1342	2.593	2.667
	21	1267	1355	2.667	2.889
	28	1260	1355	2.889	2.741
50	7	1270	1330	1.926	2.074
	14	1239	1335	2.593	2.593
	21	1225	1340	2.593	2.593
	28	1211	1344	2.882	2.519

Compressive Strength

The average compressive strength values of test cubes are presented in Figures 1 and 2 for air-cured and water-cured specimens respectively. They show that an increase in percentage of steel slag in the foamed concrete produced an increased compressive strength of the cube specimen up to 30% replacement level. Further addition of steel slag led to decrease in values of the compressive strength. This trend is attributed to the reduction in volume content of the fine aggregate at 40% and 50% slag contents (Table 3). Jones and McCarthy (2005b) and Kunhanadan and Ramamurty (2006) had earlier suggested that the compressive strength of foamed concrete increases with increase in density and decreases with decrease in density, provided other variables such as water/cement ratio, curing condition and particle sizes are kept constant. For example, at 7-day curing, the strength values are 3.04, 3.26, 3.33, 2.22 and 1.93 N/mm^2; the corresponding densities are 1267, 1280, 1300, 1314, 1275 and 1270 kg/mm^3 at steel slag contents of 0, 10, 20, 30, 40 and 50% respectively. This trend was also observed at all curing ages of 14, 21 and 28 days.

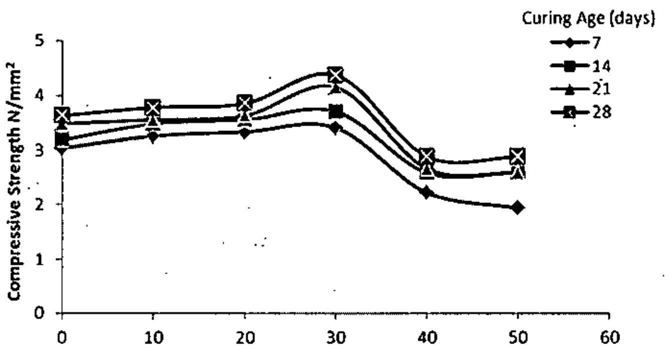

Fig 1: Variation of compressive strength of cube specimens with different slag contents at different curing ages (Air cured specimens)

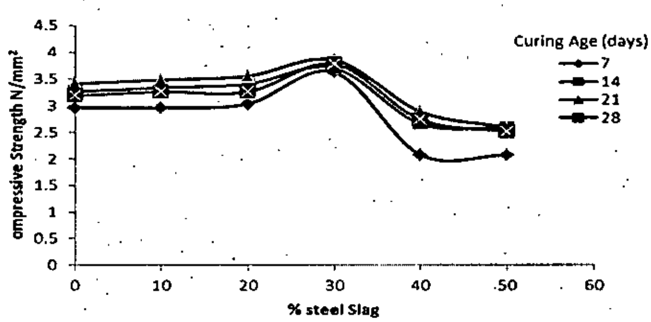

Fig 2: Variation of compressive strength of cube specimens with different slag contents at different curing ages (Water cured specimens)

Effect of Curing Method On:

Density

The curing methods affected the density of the foamed concrete. All air-cured foamed concrete specimens show continuous decrease in density with age. For example, at 10% steel slag replacement level, the densities of foamed concrete are 1280, 1257, 1255, and 1244 for 7, 14, 21 and 28 days curing ages respectively. All other percentages of steel slag replacement show the same trend. This trend may be attributed to continuous loss of water in the foamed concrete. Conversely, all water-cured specimens were found to increase in density with age. At 10% steel slag replacement level, the densities are 1323, 1334, 1353, 1379 kg/m^3 for 7, 14, 21, and 28 days respectively. This behaviour of foamed concrete in water curing environment can be attributed to the fact that foamed concrete contains voids in its internal structure. These voids are filled up when the specimens were left in water. It was observed that at all curing ages and percentages of steel slag replacement, the water cured specimens have higher densities than the air-cured specimens.

Compressive Strength

Figures 1 and 2 also show the variation of compressive strength of air-cured and water-cured cube specimens with age respectively. Figure 1 shows that strength values increased with curing ages up to 28-day for air-cured specimens. For example, at 10% replacement level of sand with steel slag the results are 3.6, 3.48, 3.56 and 3.79 N/mm^2 for 7, 14, 21, and 28 days respectively. This same trend was observed for other percentage replacements of fine aggregate with slag. Figure 2 presents the same trend of increase in strength with age for water-cured specimens up to 21- day while at 28- day there was reduction in strength values. For example at 10% steel slag content, the results are 2.96, 3.33, 3.48 and 3.26 N/mm^2 for 7, 14, 21, and 28 days respectively. The control specimens also show the same trend of increase in strength with age for both air- and water-cured specimens. Only water-cured specimens showed reduction in strength values at 28-day strength. Generally, the strength values for water cured specimen are lower than those of air cured specimens. This may be attributed to the fact that foamed concrete generally has air voids within the concrete matrix and when tested in a saturated state, the voids will be occupied by pore water which causes reduction in the strength values.

CONCLUSION

From the foregoing, the following conclusions are made:

i. The chemical composition of steel slag does not contain any compound (Cl^-, SO_4^{2-} Na_2O and K_2O) that will cause deterioration of the foamed concrete.

ii. The replacement by weight of river dredge sand with pulverized steel slag resulted into gradual reduction in the volume of aggregate in the foamed concrete mix.

iii. The concrete densities of air-cured specimens increased mildly to a maximum values at 30% replacement of the river dredged sand with pulverized steel slag for all testing days; it declines at 40% and 50% replacement.

iv. All air-cured foamed concrete specimens containing steel slag showed increase in compressive strength throughout all curing ages while water-cured specimens showed increase in strength up to 21st day curing but reduced value at 28th day

v. At 28th day, foamed concrete containing 30% steel slag developed compressive strength which is 20.3% more than the strength of the normal foamed concrete (control).

vi. Steel slag has the potential as a partial replacement of fine aggregate of up to 30% in foamed concrete

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