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Effect of Foundry Slag as Substitute in the Formulation and Evaluation of Physical Strength Properties of Portland Slag Cement

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Abstract: This research deals with the formulation and evaluation of strength properties of Portland slag cement using local foundry slag. The relative substitution of about 10 to 50 % of ordinary Portland cement for slag as an alternative cement (slag cement) to the commonly available but highly expensive ordinary Portland cement in Nigeria market. The assessment of slag substitution in ordinary Portland cement – slag cement indicated that substitution could be done to about 40 % slag addition at which 0.0158 KN/mm2 (18 %) compressive strength was obtained as compared with 0.0152 KN/mm2 (17 %) compressive strength obtained from hardened pure ordinary Portland cement after 28 days curing time. This was achieved by the data obtained when varied the substitution of ordinary Portland cement for slag from 10 to 50 %. The data were presented by statistical tools and analyzed statistically. The strength properties of slag when mixed with Portland cement were observed to be higher. Therefore, slag should be used as an aggregate or further processed into slag cement.

Key Words: Cement, Foundry slag, Nigeria, Portland, physical strength, substitute.

1 INTRODUCTION

CEMENT is a material made by burning limestone and clay which after being wetted becomes hard like stone and it is used for building, construction and so on. It can also be defined as hydraulic cement produced by pulverizing Portland cement clinker usually containing calcium sulphate (ASTM, 2001). Slag cement is commonly referred to as ground granulated blast furnace slag (GGBFS) which is hydraulic cement that works rightly with Portland cement to improve the strength and durability of concrete pavement.

Obviously, ordinary Portland cement (OPC) is the mostly consumed cement in the construction industries due to its diversified applications. It could be noted that cement contributes significant impacts on social, urban and economic development of human society but it is one of the elements responsible for carbon dioxide emission (Mehta, 1999). Thus, to reduce demand and consumption of cement, nowadays utilization of ground granulated blast furnace slag, fly ash (FA) and other pozzolans as substitute/supplement of OPC and ingredient of concrete is of utmost importance. In addition, their application in concrete construction will be the possible suggestions/solutions for the sustainable concrete production which was claimed by the several researchers.

Slag is an industrial by-product generated as waste from steel industries. Approximately, 100 million tons of slag is produced globally in a year (Nehdi, 2001). Öner et al., (2003) investigated the strength development of 1:1 mixes of clinker and granulated blast furnace slag with varying fineness of components from 3000 to 6000 cm2/g Blaine. Doğulu (1998) studied the effect of fineness of Iskenderun ground granulated blast furnace slag on its cementations' property when used as cement replacing material in Portland cement mortar with testing the 3-, 7-, 28-and 91-day flexural and compressive strengths of the mortars. Hogan and Meusel (1981) investigated the physical properties of pastes, mortars and concretes with using various granulated blast furnace slag's and slag cement combinations.

They have found that for both mortars and concretes, an optimum level of slag replacement exists for which strength is maximized and this level is approximately 50% of slag weight replacement. Öner and Akyüz (2007) studied the optimum level of ground granulated blast furnace slag on the compressive strength of concrete. According to their test results, the compressive strength of ground granulated blast furnace slag concrete increases as the granulated blast furnace slag content is increased up to an optimum point about 55 - 59 %, after which the compressive strength decreases.

The quest for using alternative Portland slag cement in place of Portland cement is an issue that is considered as part of an evolutionary life of a nation. Owing to various reasons, many countries of the world have found it necessary to formulate Portland sag cement by using local foundry slags in order to address the apparent and incessant increase in the cost of ordinary Portland cement. The reasons include; lower cost, higher strength, reduced thermal strength and to serve as a substitute to Portland cement in the market. The study is mainly in the production of Portland slag cement, which includes collection of the local foundry slag before crushing, grinding and pulverizing. It also involves the mixing of certain percentage of the slag with Portland cement by proportion.

2 MATERIAL AND METHOD

The slag sample was collected from harmony foundry along Iwo – Osogbo road, Iwo, Osun State, while ordinary Portland cement was collected at West Africa Portland Cement Plc, Ewekoro near Abeokuta, Ogun State. The equipment used for the project include Laboratory Denver Jaw Crusher, 12" X 5" Denver ball mill and End Colts EFL2MK11 Siever Shaker were obtained from Mineral Resources Engineering Department, Federal Polytechnic Ado –Ekiti, while Digital Weight Balance and Motorized California Bearing ratio (CBR) maching were obtained from Civil Engineering Department Laboratory of the Federal University of Technology, Akure.

Experimental Procedure

The first step involved was the collection of foundry slag sample. The sample was crushed on the jaw crusher and milled in the ball mill for 1 hour 30 minutes to particle size range 1.18 mm to 75 µm size. It was then sieved on the sieve shaker to a very fine particle size of 75 µm.

The samples were blended together at different proportion of 90 % of cement and 10 % slag up to the proportion of 50 % each of the sample. 40 g represented 100 % volume of ordinary Portland cement and 60.2 g (100 % by volume of slag) were blended together and mixed with 75 ml of water to form paste and moulded into four cylindrical shape container of 30 mm diameter and 50 mm height each labeled as A_1, A_2, A_3 and A_4 and allowed to set to a solid mass. The solid masses were left for 3, 7, 14, 21 and 28 days at which the compressive strengths were determined on the CBR machine for each day. Similarly, the experiments were repeated with the variations in the proportion of 90 % cement and 10 % slag, 80 % cement and 20 % slag and so on to 50 % slag and the samples were taken for the same test.

Determination of Compressive Strength

The hardened cement and slag cement paste in the mould was removed and loaded on the motorized California Bearing Ratio (CBR) machine. The handle of the machine was rotated to make the machine and the load make contact. The machine was exerted on the load thereby compressing it until the material failed under load. This was indicated by the sudden drop in the reading on the CBR meter. Then, the reading of the compressive strength was taken at the point of failure. The results were computed by using the relation below and the results presented in the tables 1 to 6.

Compressive Strength

$$= \frac{Machine\ Reading \times Conversion\ factor}{Cross\ Sectional\ Area\ of\ Specimen}$$

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Compressive Strength ($KNmm^{-2}$)

$$= \frac{Machine\ Reading \times 0.025}{\pi r^2}$$

where r = Radius of cylindrical mold = 15mm

$$r^2 = 225, \ \pi = 3.142$$

$$\therefore \quad \pi r^2 = 3.142 \times 225$$

$$= 706.95$$

$$\approx 707.$$

Compressive Strength ($KNmm^{-2}$)

$$= \frac{Machine\ Reading\ X\ 0.025\ KN}{707 mm^2}$$

3 RESULTS AND DISCUSSION

Compressive Strength Test

Table 1: Compressive strength (KN/mm^2) values obtained from the sample of 100 % pure cement after 3, 7, 14, 21 and 28 days curing time.

100 % cement	Compressive Strength (KN/mm^2) for 3 days	Compressive Strength (KN/mm^2) for 7 days	Compressive Strength (KN/mm^2) for 14 days	Compressive Strength (KN/mm^2) for 21 days	Compressive Strength (KN/mm^2) for 28 days
Sample A_1	0.0122	0.0129	0.0135	0.0143	0.0151
Sample A_2	0.0120	0.0124	0.0131	0.0138	0.0154
Sample A_3	0.0117	0.0128	0.0122	0.0141	0.0150
Average (A)	0.0120	0.0127	0.0129	0.0141	0.0152

Table 2: Compressive strength (KN/mm^2) values obtained from the sample of 90 % cement + 10 % slag after 3, 7, 14, 21 and 28 days curing time.

90 % cement + 10 % slag	Compressive Strength (KN/mm^2) for 3 days	Compressive Strength (KN/mm^2) for 7 days	Compressive Strength (KN/mm^2) for 14 days	Compressive Strength (KN/mm^2) for 21 days	Compressive Strength (KN/mm^2) for 28 days
Sample B_1	0.0120	0.0128	0.0122	0.0138	0.0145
Sample B_2	0.0121	0.0135	0.0118	0.0118	0.0141
Sample B_3	0.0117	0.0127	0.0122	0.0120	0.0145
Average (B)	0.0119	0.0130	0.0121	0.0125	0.0144

Table 3: Compressive strength (KN/mm^2) values obtained from the sample of 80 % cement + 20 % slag after 3, 7, 14, 21 and 28 days curing time.

80 % cement + 20 % slag	Compressive Strength (KN/mm^2) for 3 days	Compressive Strength (KN/mm^2) for 7 days	Compressive Strength (KN/mm^2) for 14 days	Compressive Strength (KN/mm^2) for 21 days	Compressive Strength (KN/mm^2) for 28 days

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Sample C_1	0.0108	0.0117	0.0113	0.0135	0.0149
Sample C_2	0.0106	0.0113	0.0120	0.0131	0.0149
Sample C_3	0.0108	0.0103	0.0103	0.0122	0.0141
Average (C)	0.0107	0.0111	0.0112	0.0129	0.0146

Table 4: Compressive strength (KN/mm²) values obtained from the sample of 70 % cement + 30 % slag after 3, 7, 14, 21 and 28 days curing time.

70 % cement + 30 % slag	Compressive Strength (KN/mm²) for 3 days	Compressive Strength (KN/mm²) for 7 days	Compressive Strength (KN/mm²) for 14 days	Compressive Strength (KN/mm²) for 21 days	Compressive Strength (KN/mm²) for 28 days
Sample D_1	0.0108	0.0117	0.0124	0.0130	0.0138
Sample D_2	0.0106	0.0117	0.0122	0.0120	0.0134
Sample D_3	0.0104	0.0106	0.0117	0.0123	0.0132
Average (D)	0.0106	0.0113	0.0121	0.0124	0.0135

Table 5: Compressive strength (KN/mm²) values obtained from the sample of 60 % cement + 40 % slag after 3, 7, 14, 21 and 28 days curing time.

60 % cement + 40 % slag	Compressive Strength (KN/mm²) for 3 days	Compressive Strength (KN/mm²) for 7 days	Compressive Strength (KN/mm²) for 14 days	Compressive Strength (KN/mm²) for 21 days	Compressive Strength (KN/mm²) for 28 days
Sample E_1	0.0110	0.0138	0.0158	0.0166	0.0169
Sample E_2	0.0108	0.0131	0.0152	0.0156	0.0152
Sample E_3	0.0110	0.0136	0.0149	0.0145	0.0154
Average (E)	0.0109	0.0135	0.0153	0.0156	0.0158

Table 6: Compressive strength (KN/mm²) values obtained from the sample of 50 % cement + 50 % slag after 3, 7, 14, 21 and 28 days curing time.

50 % cement + 50 % slag	Compressive Strength (KN/mm²) for 3 days	Compressive Strength (KN/mm²) for 7 days	Compressive Strength (KN/mm²) for 14 days	Compressive Strength (KN/mm²) for 21 days	Compressive Strength (KN/mm²) for 28 days
Sample F_1	0.0120	0.0124	0.0128	0.0132	0.0133
Sample F_2	0.0124	0.0120	0.0122	0.0120	0.0124
Sample F_3	0.0106	0.0121	0.0124	0.0124	0.0127

Average (F)	0.0117	0.0122	0.0125	0.0125	0.0128

Table 7: Summary of the Compressive Strength Test

Sample	Mixture content	3 days	7 days	14 days	21 days	28 days
A	100 % cement + 0 % slag	0.012	0.0127	0.0129	0.0141	0.0152
B	90 % cement + 10 % slag	0.0119	0.013	0.0121	0.0125	0.0144
C	80 % cement + 20 % slag	0.0107	0.0111	0.0112	0.0129	0.0146
D	70 % cement + 30 % slag	0.0106	0.0113	0.0121	0.0124	0.0135
E	60 % cement + 40 % slag	0.0109	0.0135	0.0153	0.0156	0.0158
F	50 % cement + 50 % slag	0.0117	0.0122	0.0125	0.0125	0.0128

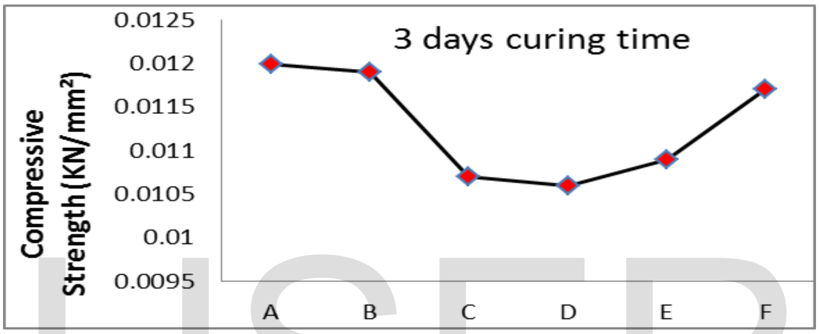

Fig. 1: Graph of compressive strength of 3 days for each sample A - F

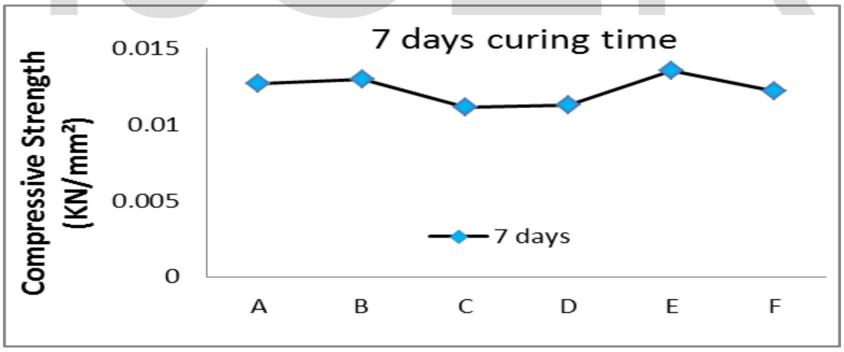

Fig. 2: Graph of compressive strength of 7 days for each sample A - F

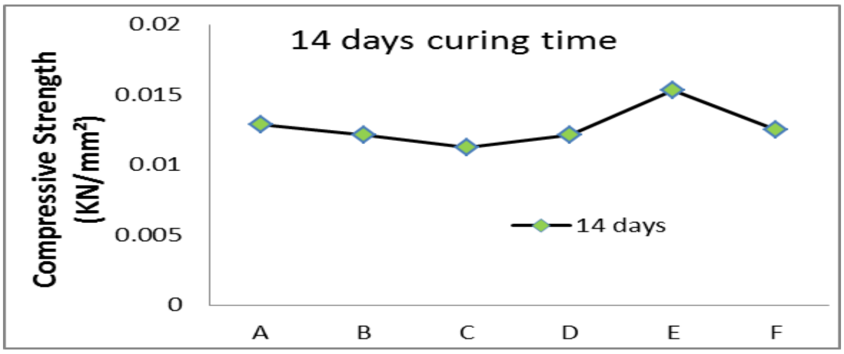

Fig. 3: Graph of compressive strength of 14 days for each sample A – F

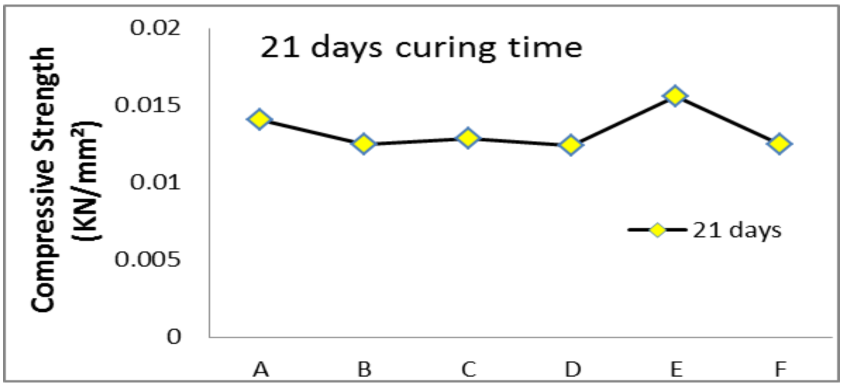

Fig. 4: Graph of compressive strength of 21 days for each sample A - F

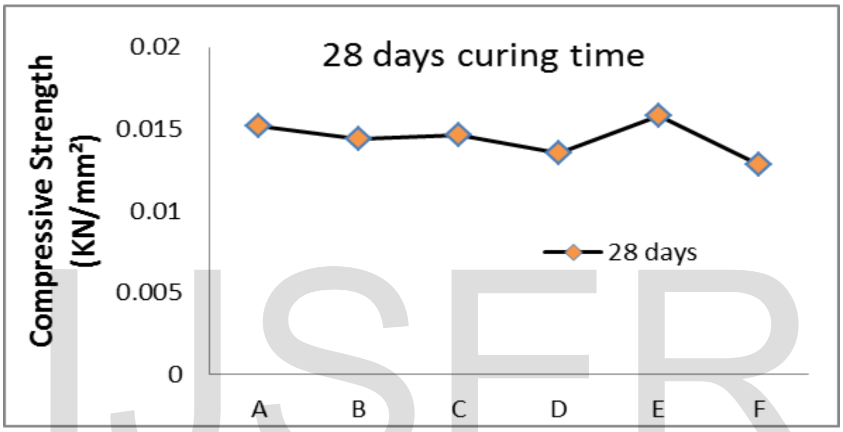

Fig. 5: Graph of compressive strength of 28 days for each sample A - F

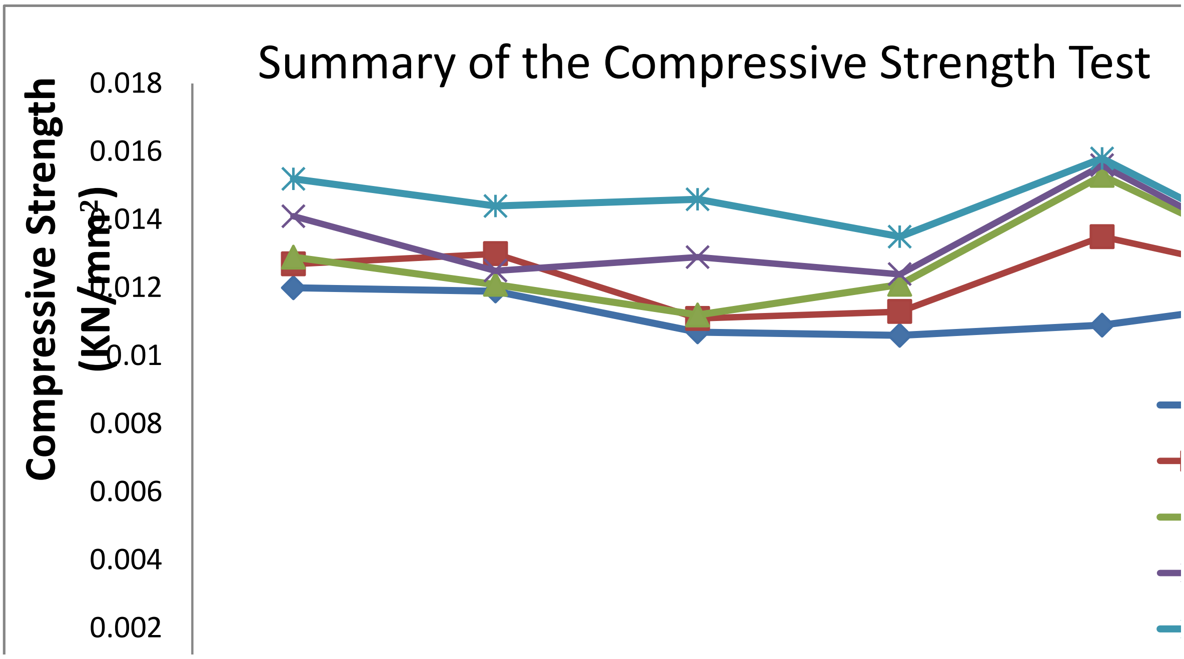

Fig. 6: Summary of compressive strength for samples A – F for 3, 7, 14, 21 and 28 days

4 DISCUSSION

From the result above, fig 1. reveals that the compressive strength of sample A (100 % pure cement) decreases rapidly in the first 3 days, this shows early strength development while it later increases from sample E (60 % cement + 40 % slag) to sample F (50 % cement + 50 % slag) within 3 days of curing time. Fig. 2 shows little diference from Fig. 1, sample B (90 % cement + 10 % slag) maintains the highest compressive strength of 7 days curing time and sample E (60 % cement + 40 % slag) experiences increase in compressive strength. Fig. 3 shows that sample E (60 % cement + 40 % slag) has the highest compressive strength of 14 days curing time. Similarly, fig. 4 and 5 indicate that the same sample E (60 % cement + 40 % slag) has the highest compressive strength after 14 – 28 days curing time.

Fig. 6 shows relatively overall similar parttern of behaviour of increasing compressive strength with increasing curing time of slag substitution from 0 - 50 % for samples A – F. It is shown that there is an increase in the compressive strength of pure ordinary Portland cement mix from 0.0152 KN/mm^2 to 0.0158 KN/mm^2 as the curing time increased from 3 – 28 days. This actually conforms to the results commonly obtained in the use of ordinary Portland cement. Generally, after 7 days, the compressive strength values of the Portland slag cements starts to increase and reaches about the 90 % of the Portland cement control specimen values (Yousef and Vefa, 2012). This means that further curing time will enhance further increase in compressive strength and this makes sample E (60 % cement + 40 % slag) to be more suitable than the rest.

5 CONCLUSION

The results obtained show that percentage of slag ranging from 20 – 50 % play a major role in workability and durability of concrete. The assessment of slag substitution in ordinary Portland cement to slag cement indicated that substitution could be done to about 40 % slag addition at which 0.0158 KN/mm^2 (18 %) compressive strength was obtained as compared with 0.0152 KN/mm^2 (17 %) compressive strength obtained from hardened pure ordinary Portland cement after 28 days curing time. Therefore, moderate percentage addition of slag to ordinary Portland cement should be used since the properties of slag cement come out with reasonable results.

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