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INVESTIGATING THE EFFECTS OF THERMAL VARIANCE ON THE PROPERTIES OF SLAG CEMENT CONCRETE

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ABSTRACT

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder, this research investigates the effects of temperature variation on the strength properties of slag cement concrete. Concrete samples were prepared with slag cement concrete and cured for 28 days, after curing, the concrete samples were removed, weighed and tested with rebound harmer to determine the concrete compressive strength. Some samples were selected and heated at varying temperatures of 100, 150, 200, 250 and 300^{0}C, thereafter, the samples were weighed and testing with the rebound harmer to determine the effects of temperature on the mass and strength of the slag concrete. The results of experimental works show that, slag cement concrete was found that concrete losses it mass, density, hardness and compressive strength with increase in temperature. The thermal performance of Slag

Introduction

Durability of concrete is its ability to resist abrasion, weathering action, chemical attacks and all other forms of deterioration. Durable concrete performs satisfactorily under anticipated exposure condition during it lifespan [1]. Some factors affecting the durability of concrete includes, ingress water permeability, carbon dioxide, sulphates, chlorides, oxygen and other deleterious substances which results to cracks and voids emanating during production and service (Mehta and Monteiro, 2006). The effects of heat of hydration, sulphate attack, carbonation, moisture movement, pozzolanic action, shrinkage types, chloride effects, steel corrosion and many other aspects comes under preview of

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cement concrete was found to be slightly higher than that of normal concrete in terms of tensile properties, also, elevated temperatures produce adverse effects on the density and strength of concrete.

Keywords: Effects, Thermal Variance, Properties, Slag Cement, Concrete.

Volume changes [2, 3].

Ground-granulated blast-furnace slag (GGBS or GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel-making) from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder. The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminates impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production, the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation. Slow cooling of slag melts results in an uncreative crystalline material consisting of an assemblage of Ca-Al-Mg silicates [4, 5, 6].

In attempts to improve the strength of concrete, many additives have been used. Additives are natural or manufactured chemicals which are added to concrete before or during mixing to enhanced it properties. The most often used additives are air entraining agents, water reducers, accelerators, retarders e.t.c. Also, different types of cement apart from Portland cement such as sulphate resistance cement, high alumina cement slag cement have been used to improve the performance of concrete. For this research, Ground Granulated Blast-Furnace Slag (GGBS) cement will be used as a binder [7].

Nondestructive testing has been widely used in the construction industry to test the properties (strength properties) of materials or structures, the differences in structural defects and characteristics, and the quality of materials and structures during and after construction and within the service life of the structure. This system of testing has been proven to be easy, quick and still gives a reliable result of the tested concrete structure or sample. Above all, it serves various testing purposes beyond being an effective testing tool for inspection and measuring of the strength and quality of hardened concrete or an existing concrete structure [8, 9]. Rebound hammer has been used in the past to measure the compressive strength of concrete and establish the quality of concrete structures. It is also employed to establish the characteristics of material properties and evaluation of structural defects for existing structures due to time and environmental factors. These tests are usually done without causing internal or physical damage to the structure or product; ideally, the test method is cheaper and less time-consuming [10, 11, 12]. Since there is no sample loaded directly until failure occurs, the strength of materials using the nondestructive test is derived based on estimation, and no absolute strength value is provided [13].

In the Schmidt rebound hammer, mechanical parts (i.e. springs, sliding hammer mass, etc.) provide the impact load and mechanical (Original Schmidt hammer) or digital (DIGI-Schmidt hammer, Silver Schmidt hammer) parts are responsible for readings. The value of the Schmidt rebound index depends on energy losses due to friction during acceleration and rebound of the hammer mass and that of the index rider, on energy losses due to dissipation by reflections and attenuation of mechanical waves inside the steel plunger; and of course, on energy losses due to dissipation by concrete crushing under the tip of the plunger. This latter loss of energy makes the Schmidt rebound hammer suitable for strength estimation of concrete [14, 15, 16]. The energy dissipated in the concrete during local crushing initiated by the impact depends on the properties of the concrete in the very vicinity of the tip of the plunger. Therefore, the measurement is sensitive to the scatter of local strength of concrete due to its inner heterogeneity [16, 17]. The amount of energy dissipated in the concrete can be higher for a concrete of lower strength/lower stiffness compared to lower energy dissipation in a concrete of higher strength/higher stiffness. As it is possible to prepare concretes of the same strength but having different Young's modulus, it is also possible to measure the same rebound index for different concrete strengths or to measure different rebound indices for the same concrete strengths. Young's modulus of the aggregate has considerable influence on the rebound index. The most significant influence on strength of concrete was found to be the water-to-cement ratio (w/c) of the cement paste [17, 18, 19].

Several approaches have been adopted in relating the results of hardness test in estimating the strength of concrete [20] in their research made samples from ordinary Portland Cement and aggregate of local natural sources or crushed hard limestone. Various concrete mixes were used to prepare the standard cube specimens (15 × 15 × 15 cm3) in the laboratory to compare with Schmidt Hammer manufacturer's calibration curve. Cube specimens were taken from the water on 28-90 days and rubbed with a dry cloth to obtain a surface dry sample. Two opposite faces of the cubes were prepared for the Schmidt Hammer test when drying was completed. The specimens were placed in the testing machine and slight load (7 NM/m2) was applied [21].

Afterwards, a fixed amount of energy was applied by pushing the hammer against the test surface according to the ASTM C 805 (1993) and TS 3260 (1978). Each of the two opposite faces of cubes was impacted to get at least 24 readings to illustrate the sensitiveness of the test to the presence of aggregate and voids immediately underneath the plunger. Average of rebound numbers and standard deviations were calculated. A correlation was set up and illustrated with data obtained from 28, 90 days and in situ

core specimens used for concrete strength and Schmidt rebound hammer tests. When Schmidt Hammer test on each cube specimen was completed, the load was applied up to failure. The outcomes were found to be harmonious [22, 23, 24, 25]. Also, the 28-days specimens R^2 value is found to be 0.856 and its equation is y= 11.612A–52.033 (where y, compressive strength; A, rebound number). R^2 value of 90-days specimens is found to be 0.9449 and its equation is y = 16.674A–238.31.
Schmidt Hammer test results can be influenced by many factors; such as the characteristics of the mixture, surface carbonation, moisture condition, rate of hardening and curing type. Therefore, the correction factors have to be used to allow this effect for existing concrete. Schmidt Hammer rebound tests can be used to estimate the strength of concrete with calibration curves to reduce the number of cores taken from the structures [27, 28, 29]. As long as this calibration is done properly, there would be even no reason to get the core in situ. Nevertheless, it is important to understand that several factors should be in place when evaluating concrete structures using the Schmidt rebound hammer test. Factors such as the surface irregularity of sample, space between impact, surface hardness, age of the concrete sample, moisture of sample, presence of void and calibration of Schmidt rebound hammer were used to evaluate the relationship between nondestructive (Schmidt rebound hammer test) and destructive test on compressive strength of concrete. Evaluation of compressive strength and other strength properties of concrete using conventional direct tests such as compressive strength testing (using a compressive machine) is expensive, labor-intensive and time-consuming [30, 31, 32]. On the other hand, reported studies have shown that the Schmidt rebound hammer test is reliable in the prediction of concrete strength when used in the correlation between Schmidt rebound hammer result and compressive strength of concrete [33, 34]. Higher compressive strength produces higher rebound number while lower compressive strength produces lesser compressive strength ([35, 36, 37, 38].

Materials and Methods

Mass and Density Test

Density is expressed as the mass per unit volume of concrete. Density is a reflection of weight as concrete gain strength. The following apparatus were used, weighing balance or scale; tamping rod, which is a round straight steel.

Procedure

Concrete cubes of 100mm x 100mm were casted and cured for 28 days after which the cubes were removed. The volume of the cubes was estimated as $0.001m^3$. The cubes were weighed with a weighing balance and the mass was recorded.
The density of the concrete shall be calculated as

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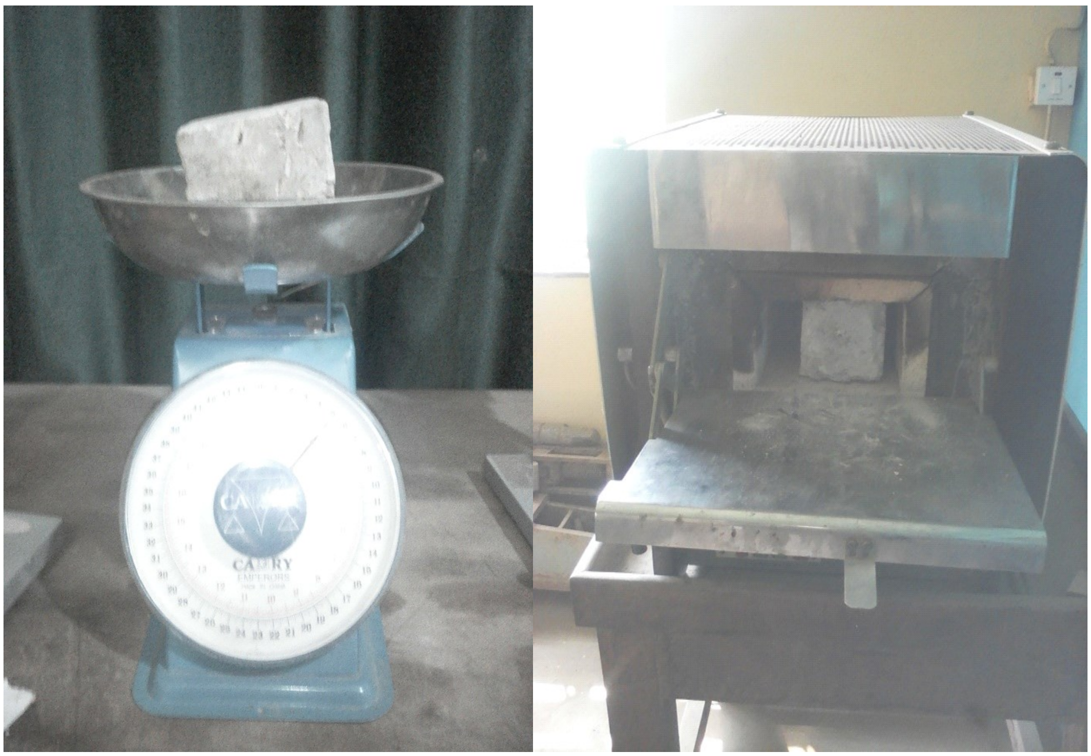
Density = Mass/Volume

Concrete cubes were selected and subjected to heat at varying temperatures of 100^{0}C, 150^{0}C 200^{o}C, 250^{o}C and 300^{o}C at intervals of 30 minutes, 45 minutes and 60 minutes. The weights of the cubes were measured again and the density was calculated to determine if the density of the concrete was affected by temperature rise.



(a) (b)

Figure 1.0: Testing for the mass of the samples

Heating of the samples in a furnace

Molds: Molds used for preparing samples were in agreement with the standard if the following conditions satisfy:

Sampling: The first step was to take a test sample from the large batch of concrete. This was done as soon as the discharge of the concrete commences. The sample was representative of the concrete supplied.

Tamping Rods: Tamping rods were used to distribute the concrete evenly prior to the start of consolidation. Two sizes are specified in ASTM methods. Each size shall be round, straight steel rod with at least the tamping end rounded to a hemispherical tip of the same diameter as the rod. Larger rod, 6/8 in. (16 mm) in diameter and approximately 24 in. (600 mm) long can be used for tamping.

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Mixing: Mixing of the concrete was done by hand.

(i) The cement and fine aggregate were mixed on a water tight none-absorbent platform until the mixture was thoroughly blended and is of uniform color

(ii) The coarse aggregate was added and mixed with cement and fine aggregate until the coarse aggregate was uniformly distributed throughout the batch

(iii) Water was added and mixed it until the concrete appears to be homogeneous and of the desired consistency

Curing of Cubes: Test specimens were stored in moist air for 24 hours and after this period the specimens were marked and removed from the molds and submerge in a clean fresh water for 28 days.

Procedure for Cube Test

(I) The specimen was removed from water after specified curing time (28 days) and wipe out excess water from the surface.

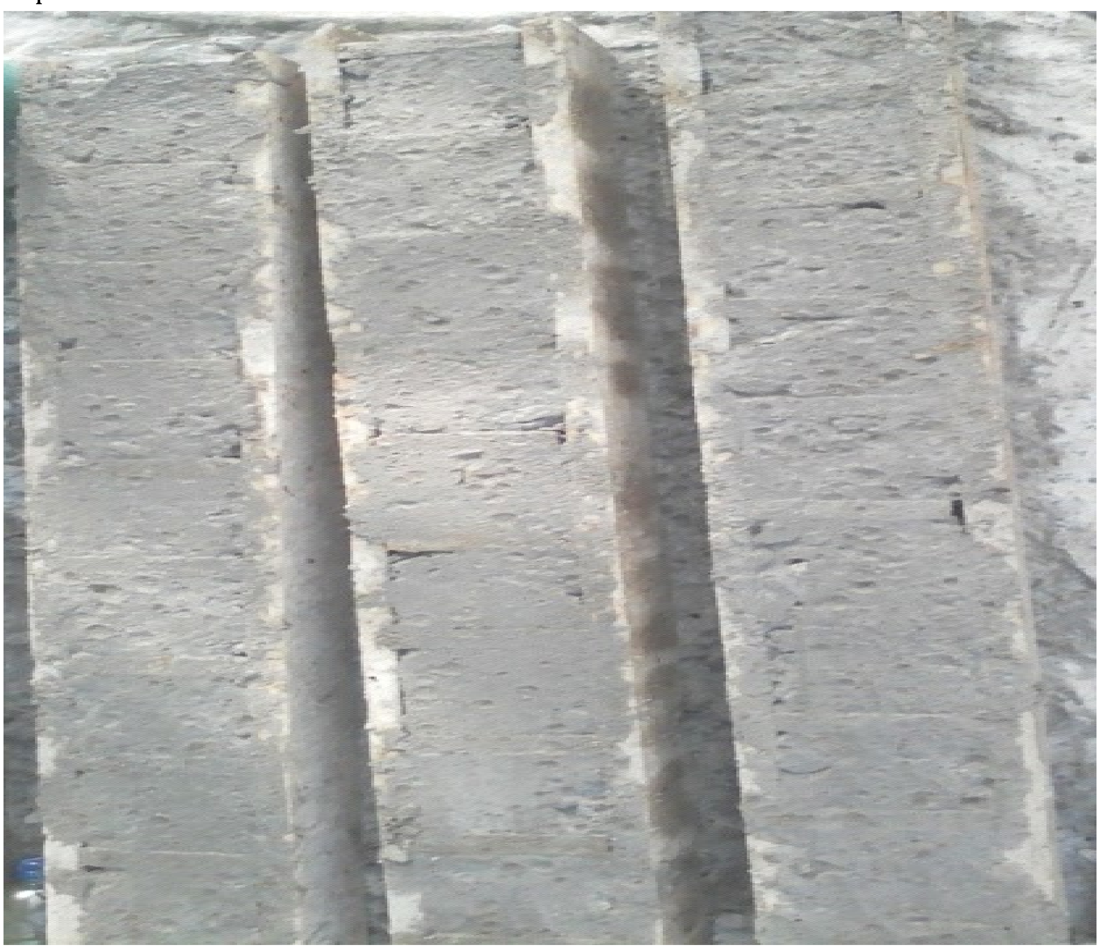

Figure 2.0: Concrete samples

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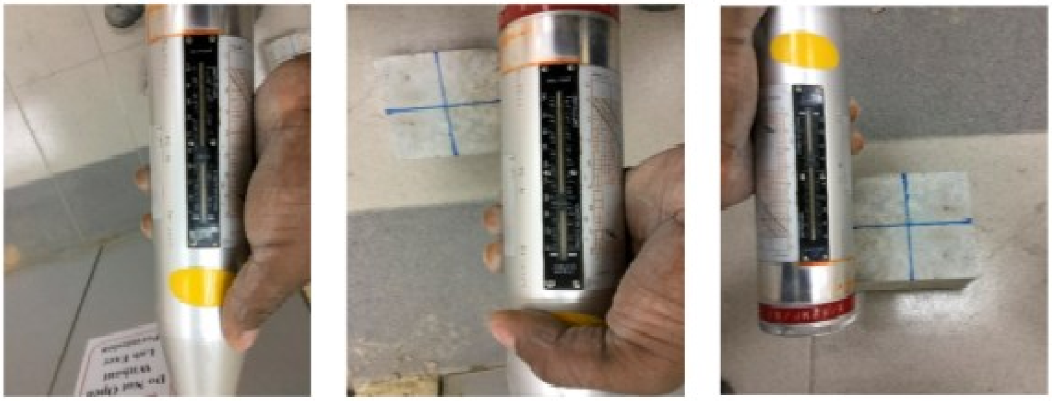

Figure 3.0: Rebound hammer reading after testing on concrete sample using rebound hammer method

Table 1.0: Interpretation of rebound hammer test results

Rebound Number	Quality of Concrete
More than 40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
Less than 20	Poor concrete
0	Delamination

Results/Discussion

Below shows the mass of the concrete samples under thermal conditions

Table 2.0: Density Test Results

Temperature ^{0}C	Time M	Average mass g
0^{0}C		2513.97
100^{0}C	30	2437.00
	45	2428.00
	60	2426.33
150^{0}C	30	2428.33
	45	2401.00
	60	2383.33
200^{0}C	30	2381.67
	45	2340.67
	60	2337.33

250⁰C	30	2372.67
	45	2351.33
	60	2336.33
300⁰C	30	2314.67
	45	2281.33
	60	2166.33

Table 3.0: Hardness Test Results

The table below shows the result of hardness test carried out on the concrete samples at varying temperature and time

Temperature (⁰C)	Time (Minutes)	Compressive Strength N/mm² using Rebound Number
0⁰C		25.32
100⁰C	30	33.51
	45	34.10
	60	35.10
150⁰C	30	36.57
	45	37.50
	60	36.85
200⁰C	30	36.00
	45	35.55
	60	35.14
250⁰C	30	36.80
	45	36.14
	60	35.60
300⁰C	30	35.10
	45	34.65
	60	33.55

A correlation of the direct measurements of surface hardness for the same points of the structure at which the concrete specimens were collected and the specimens' compressive strengths established was used in this work. It was also observed that the maximum loss in compressive strength was 0.45% at 100⁰C, 1.75% at 150⁰C, 2.67% at 200⁰C, 5.98 at 250⁰C and 12.04% at 300⁰C. Also, the maximum loss in bond strength was 0.72% at 100⁰C, 1.05% at 150⁰C, 2.49% at 200⁰C, 9.7% at 250⁰C and 19.67% at 300⁰C, Normal concrete losses over 20% of its compressive and bond strength at 300⁰C. This shows that Slag cement has a considerable higher resistance to heat attack than Ordinary

Portland Cement in terms of both compressive and bond strength. The loss of strength due to wetting of a compression test specimen is caused by the dilatation of the cement gel by adsorbed water: the forces of cohesion of the solid particles are then decreased. Conversely, when on drying the wedge-action of water ceases, an apparent increase in strength of the specimen is recorded. The lower strength of the saturated concrete is attributed to the disjoining pressure within the cement paste. According to [23, 25, 39], it may have something to do with the change in the structure of the C-S-H on drying, or it may simply represent a change in the internal friction and cohesion on a macroscopic scale; that is, moisture may have a lubricating effect, allowing particles to slip by each other in shear more easily. The lower compressive strength of wet concrete may also be due to the development of internal pore pressure as a load is applied.

Conclusion

From the research, the following conclusions were made

1. The stronger the concrete, the higher the surface hardness index
2. Slag cement concrete was found that concrete losses its mass, density, hardness and compressive strength with increase in temperature.
3. The thermal performance of Slag cement concrete was found to be slightly higher than that of normal concrete in terms of tensile properties.
4. Elevated temperatures produce adverse effects on the density and strength of concrete.
5. The compressive strength of slag cement concrete was found to be considerably higher than Portland cement as already established by other researchers. When concrete is heated gradually, loss of weight appears to take place in two stages, namely, the drying stage, evaporation of water from large capillaries and voids will take place. At the dehydration stage, which occurs loss of non-evaporated water from the gel pores and small capillary pores will take place.

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