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INVESTIGATION OF THE EFFECTS OF TEMPERATURE VARIATION ON THE COMPRESSIVE STRENGTH OF PORTLAND CEMENT CONCRETE AND SLAG CEMENT CONCRETE

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Abstract
This study investigated the thermal resistance of Slag Cement Concrete. Slag cement is an environmentally friendly alternative to Portland cement. Heat from fire alters the physical and mechanical properties of concrete. Given the decisive role of thermal resistance in the operation and performance of structures, it is necessary to evaluate the effect of heat on the performance of Slag Cement concrete. In this study, Compression Tests, and Density Test were carried out to examine the effects of heat on some mechanical properties of Slag Concrete. Concrete cubes and cylinders consisting of granite, sand as coarse and fined aggregates and slag cement as a binder were prepared and The concrete samples were cured for 28 days after which were subjected to varying temperatures of 100, 150, 200, 250 and 300˚C at 30, 45 and 60 minutes and the change in their compressive strength was measured and compared. The result of the experiment shows that the loss in compressive strength of the slag cement concrete was 0.45% at 100^{o}C, 1.75% at 150^{0}C, 2.67% at 200^{0}C, 5.98 at 250^{0}C and 12.04% at 300^{0}C, while that of ordinary Portland cement was 0.29% at 150^{0}C, 1.01% at 200^{0}C, 5.88% at 250^{0}C and 12.07% at 300^{0}C. It was observed that higher temperatures exert adverse effects on the strength of concrete. The compressive strength of slag cement concrete was found to be considerably higher than Portland cement as already established by other researchers. From the results, it was observed that below the temperature of 250^{0}C both concrete did not lost significant Strength, in fact, Portland cement gain 0.67% strength at 100^{0}C, but from 250^{0} and above, there was a significant loss of strength. The results show

that Slag Concrete has a good thermal resistance ability and as such can be suitable even in industrial areas.

Introduction

Slag cement is a hydraulic binder obtain by blending ground granular blast furnace slag with Portland cement or cement clinkers. Slag is an industrial bye product of steel. Slag cement was first used when granulated slags were combined with lime to produce cement mortals. It was first produce in 1896 in the United States. Blending of granulated slags with Portland cement was later done in 1950s. Research have shown that concrete mechanical properties are improved and performs better at replacement ratios of 25-50% slags. Slag cement have been used in almost all concrete construction works such as, foundation works, concrete pavements, high performance concrete etc. just like Portland cement concrete.

According to slag cement Association (SCA), concrete produced by blending granular slags with Portland cement has been known to improve workability, lower setting time of concrete than that of ordinary Portland cement. Researchers have also established that slag cement concrete has higher compressive and flexural strength than that of ordinary Portland cement which minimizes the cracking tendencies of concrete and increase its suitability in high performance concrete. Slag cement is also discovered to have considerably lowers the permeability of concrete owing to the fact that it has less penetration of sulphates and chlorides into the concrete and reduces the corrosive risk of the steel reinforcement.

Slag concrete is also known to have higher resistance to chemical attacks than ordinary Portland cement and as such its durability in chemically aggressive areas is higher than that of Portland cement (S. Terlumun et al 2022). Slag cement ability to improve the mechanical properties of concrete has made it gain a wide acceptance in the construction industry. The use of slag cement also reduces greenhouse effects in concrete construction and as such is more environmental friendly than Portland cement (SCA).

However, its response to thermal conditions need to be carefully studied to assess it performance under thermal conditions. For example, it ability to withstand fire attacks before collapse and whether it can be used under elevated temperature conditions such as design and construction of furnace etc. This research focus on the thermal performance of slag cement concrete. In this work, density and compressive strength of concrete has been assess on both slag cement and ordinary Portland cement concrete at various temperatures and time intervals (Ajagbe et al 2020).

Methodology

Materials

Steel slag

Blast furnace slag is a bye-product of the steel production process was obtained at Prism Steel Company Ikirun, Osun State Nigeria. The steel slag was crushed and grinded to powdered form. The granulated ground granular blast furnace slag was further sieved with 50µm size of BS sieve to obtain a more powdered form which was used for the preparation of the binder.

Binder

Two kinds of binder were used in this work, The Ordinary Portland Cement used was Dangote cement which was source from a retailer in Bodija market, Ibadan, Oyo State, Nigeria and it conformed to the standard of BS EN 197-1:2000. Also slag cement which was prepared by blending 30% of the Granulated Ground Granular Blast Furnace Slags with 70% Ordinary Portland cement.

Fine and Coarse aggregates

The fined aggregates used for this work was sharp sand. The sand was sourced from a construction site in Faculty of Technology, University of Ibadan. The sand was free from dirt and organic matters. The coarse aggregates used for this research is granite. The aggregates sizes was 10mm. The aggregates were cleaned from all physical impurities. It was sourced from a construction site in Faculty of Technology, University of Ibadan.

Water

The water used for this research is University of Ibadan water which was clean, free from impurities and drinkable.

Aggregates Test

Sieve Analysis

Sieve analysis was first carried out on both the fined aggregates (sand) and the coarse aggregates (granite) to determine the particle size distribution. The aggregates samples were first weighed to a mass of 500g for fined aggregates and 3000g for coarse aggregates. The BS sieves were arranged in order of decreasing size from top to bottom and the dry mass of the samples were placed on top of the sieves. The sieves were thoroughly for the minimum time required to provide complete separation of the aggregates according to size (approximately 10 minutes). The individual and cumulative mass retained on each sieve and the pan to the nearest 0.1 percent. During the process, it was ensured that all the materials trapped in full openings of the sieves were cleaned out and included in the mass retained.

Figure 1 (a) coarse aggregates

Figure 1(b) Concrete cubes

Concrete Test

Concrete and Sample Preparation

Molds: Molds used for preparation of samples are in agreement with the standards. Molds of size 100mmX100mmX100mm were used for the casting of the concrete cubes.

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. The coarse aggregate was added and mixed with cement and fine aggregate until the coarse aggregate was uniformly distributed throughout the batch. Water was added and mixed it until the concrete appears to be homogeneous and of the desired consistency. The molds were thoroughly cleaned and greased with oil to aid removal of formwork. The concrete was filled in the molds in layers approximately 5cm thick each layer was compacted with not less than 35strokes per layer using a tamping rod (steel bar 16mm diameter and 60cm long, bullet pointed at lower end). The top surface was levelled and smoothen with a trowel. Test specimens were stored in moist air for 24 hours and after this period the specimens were marked and removed from the molds and cured by total immersion in a clean fresh water for 28 days.

Density Test

Density is expressed as the mass per unit volume of concrete. Density is a reflection of weight as concrete gain strength. The apparatus used were, weighing balance, tamping rod. Concrete cubes of 100mm x 100mmX100mm were casted and cured for 28 days after which the cubes were removed. The volume of the cubes were estimated as $0.001m^3$. The cubes were weighed with a weighing balance and the mass was recorded. The density of the concrete was calculated as

Density = Mass/Volume

Concrete cubes were selected both for the slag cement concrete and the ordinary Portland cement and subjected to heat at varying temperatures of 100^0C, 150^0C 200^oC, 250^oC and 300^oC at intervals of 30 minutes, 45 minutes and 60 minutes. The mass of the cubes were measured again and the loss in strength was calculated to determine the effects of temperature rise on the density of the concrete.

Figure 2 Testing for the mass of the samples before and after heating

Figure 3 Heating of the samples in a furnace

Figure 4 Compression Test of Concrete Cubes

Compression test

Procedure for Cube Test

The specimen was removed from water after specified curing time (28 days) and excess water from the surface was wiped out. The dimension of the specimen were carefully taken and recorded. The bearing surface of the testing machine was thoroughly cleaned. The specimen was placed in the machine in such a manner that the load can be applied to the opposite sides of the cube cast. The specimen was aligned centrally on the base plate of the machine. The movable portion was rotated gently by hand so that it touches the top surface of the specimen. The load was applied gradually without shock and continuously until the specimen fails. The maximum load was recorded and noting any unusual features in the type of failure.

After testing for 28 days strength, some concrete was selected and then heated at various time intervals of 30 minutes, 45 minutes and 1 hour to varying temperatures of 100^0C 150^oC, 200^oC, 250 and 300^oC and the same procedure for cube test was carried out to determine the effects of heat on the compressive strength of the concrete. In each case the compressive strength of the concrete was calculated.

RESULTS: Mass and Compression Test Result

Table 1.0 Result of the mass and compressive strength for both concretes

Temp (0C)	Time Mins.	Comp. Stgh. N/mm^2	Comp. Stgh. N/mm^2	Mass (g) OPC	Mass (g) SCC
0^0C		23.86	25.12	2408	2513.97
100^0C	30	23.80	25.05	2406	2437.00
	45	23.90	25.04	2403	2428.00
	60	24.02	25.06	2401	2426.33
150^0C	30	24.00	24.80	2402	2428.33
	45	23.95	24.80	2394	2401.00
	60	23.92	24.68	2381	2383.33
200^0C	30	23.94	24.63	2366	2381.67
	45	23.80	24.47	2350	2341.67
	60	23.62	24.45	2341	2338.33
250^0C	30	23.61	24.33	2340	2376.67
	45	23.22	24.05	2302	2353.33
	60	23.40	23.67	2276	2338.33

300⁰C	30	22.10	24.03	2307	2346.00
	45	21.80	23.60	2250	2328.10
	60	20.98		2221	2299.02

Calculations for Concrete Cube Tests for Compressive Strength

Compressive strength of the specimen is calculated by dividing the maximum load carried by the specimen during the test with the average cross-sectional area.

Size of the cube =10cm x10cmx10cm. Area of the specimen (calculated from the mean size of the specimen) =100cm^2

Maximum load applied in tones were converted to Newton.

Compressive strength = (Load (P) in N/ Area (A) in mm^2)

Where P is the maximum load at which the specimen fails while A is the area of the cube. Characteristic compressive strength (f_{ck}) at 28 days would be calculated and recorded. Average compressive strength of the concrete cubes in N/mm^2 (at 28 days) would be read and recorded.

Discussion/conclusion

From this research, the following conclusions were made:

1. Slag cement concrete has a considerable higher compressive strength than Ordinary Portland cement. It was observed that from a temperature of 100-200^{0}C, there was no significant effects of temperature on the mechanical properties of the slag concrete. Compressive strength was (0.29-2.67), which was negligible.

2. Above a temperature of 200^{0}C and up to 300^{0}C the effects of temperature on the compressive strength concrete became significance. At 250^{0}C (5.98%) at 60 minutes but was still not significance at 30 and 45 minutes (3.15-4.27%) , but at 300^{0}C, a significance effect was noticed from 45 minutes to be 6.10%. The higher the temperature, the lesser the compressive strength. The time interval at which the concrete was subjected to heat has a significance influence on the concrete strength, the more the concrete stays under heat, the lesser the strength.

3. Slag Cement concrete has slightly higher but approximately the same thermal resistance ability as compared to Ordinary Portland Cement. Hence, Structural design for fire safety for Ordinary Portland Cement can be applicable for slag cement.

4. Owing to the fact that slag cement has a good strength, durability, workability and chemical resistance attack than Portland cement, I recommend that slag

cement be used in Nigeria especially in the South-South Part of the nation that the environment is chemically aggressive due to the presence of crude oil and other mineral resources. Also some parts of Northern Nigeria like Sokoto for example where environmental conditions are not favorable for Portland cement.
5. Higher temperature values should be used to examine much of the effects of temperature on the strength and properties of concrete. Other mechanical properties like, flexural strength, fracture toughness etc. should also be investigated to properly examine the performance of slag cement on thermal conditions.

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