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EVALUATION OF THE EFFECTS OF HEAT ON THE HARDNESS AND COMPRESSIVE STRENGTH OF SLAG CEMENT CONCRETE

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Abstract: This study investigates the thermal resistance ability of slag cement concrete. Heat from fire changes the physical, chemical and mechanical properties of concrete. Given the decisive role of thermal resistance in the operation and performance of concrete structures, it is necessary to evaluate the effect of heat on the performance of slag cement concrete. In this study, compression and hardness tests were carried out to examine the thermal resistance of slag concrete. Concrete cubes were prepared and cured for 28 days after which the samples were subjected to varying temperatures of 100, 150, 200, 250 and 300°C at 30, 45 and 60 minutes and the change in their hardness and compressive strengths were measured and compared with that of ordinary Portland cement concrete. The result of the experiment shows that the loss in strength was 0.45% at 100°C, 1.75% at 150°C, 2.67% at 200°C, 5.98 at 250°C and 12.04% at 300°C, the hardness was found to be increasing from 100 to 150°C but decreased with higher temperatures. But Normal concrete losses over 20% of its compressive strength at 300°C. This implies that higher temperatures exert adverse effects on the strength of concrete. From the results, it was observed that below the temperature of 250°C the concrete did not lost significant strength however, from 250°C and above, there was a significant loss of strength. The results show that slag concrete has slightly higher thermal resistance ability and as such can be suitable even in industrial areas.
Keywords: Effects, Heat, Compressive Strength, Hardness, Slag Cement, Concrete

INTRODUCTION

Any construction work requires a few materials, for example, solid, steel, block, stone, glass, mud, mud, wood e.t.c. Notwithstanding, the cement concrete remains the major construction material utilized by construction companies. The expanding requirement for cement concrete construction has had a natural effect including around 7 percent offer of CO_2 outflows to the environment [1,7]. One answer for environmental friendly concrete production is to utilize Slag Cement Concrete which is delivered by blending Ground Granular Blast Furnace Slag (GGBS) with Portland Cement or through the expansion of clinkers to GGBS.

Fire reaction of cement auxiliary individuals is reliant on the thermal, mechanical, and deformation properties of cement concrete. These properties vary considerably with temperature and furthermore depend upon the composition, characteristics of concrete batch mix and heating rate and other natural or environmental conditions

Fire is a standout amongst the riskiest phenomena that a structure might experience during its lifetime. The performance of normal concrete at high temperatures has extensively been investigated and its characteristics have been well-established [2-3].

The decrease of quality of ordinary cement because of physical and chemical changes in the microstructure of cement is caused by changes in hydration products. By raising the temperature, a lessening in the compressive strength of concrete will occur. Up to 300°C, fine splits are seen on the concrete surface. At temperatures over 400°C, calcium hydroxide (CaOH2) is decomposed to different items. Calcium silicate gel (C-S-H) as the significant segment of cement paste and the fundamental factor affecting the quality of cement is disintegrated at 600°C. With deterioration of hydration products at 800 °C concrete totally loosed its compressive quality. The aim of this study is to investigate the thermal capacity of blast furnace slag cement after heating at 100, 150, 200, 250, and 300°C.

Stress-strain reaction of essential materials at elevated temperatures, tensile strength, compressive strength and modulus of elasticity are the main mechanical characteristics that ascertain the fire performance of members of reinforced concrete.

Compressive strength of concrete at high temperature is of primary enthusiasm in fire safety design.

At ambient temperature, the compressive strength of concrete is a function of aggregated type and size, admixture types, water-cement ratio, aggregate-paste interface transition zone, type of stress and curing conditions. At elevated temperature, concrete compressive strength is significantly affected by binder in batch mix (fly ash, slag and silica fume), rate of heating and room temperature strength. While concrete mechanical properties are thoroughly researched, there is significant paucity of research with respect to the thermal properties of cement concrete at high temperature. Thus, a research gap that needs to be filled. The strength degradation in HSC is not consistent and there are significant variations in strength reduction, as established by various authors.

MATERIALS AND METHODS

— Materials

The materials used for this work were, well graded sand obtained at the University of Ibadan, the coarse aggregates used was granite obtained at a quarry plant in Ibadan While the binder used was slag cement prepared by blending 50% of GGBS and OPC.

— Methods

Preparation of Sample

Slag was obtained from the Prism Steel Company Ikirun, the slag was crushed and grounded into powdered form which was used to prepared the binder. The binder used for this work was prepared by blending 50% of GGBS with Ordinary Portland Cement. The fine aggregates and the cement were thoroughly mixed on non-absorbent surface until the mixture was properly blended giving a uniform colour after which coarse aggregates was added with cement and fine aggregate until the coarse aggregate was uniformly distributed throughout the batch. Water was added and mixed until the concrete appears to be homogeneous and of the desired consistency.

Compressive and Hardness Test

The moulds were thoroughly cleaned and greased with oil to aid removal of formwork, the concrete was filled in the molds in layers approximately 5cm thick and each layer was compacted with not less than 35strokes per layer using a tamping rod, the top surface was leveled and smoothen it with a trowel. The test specimens were stored in moist air for 24 hours and after this period the specimens were removed from the moulds and submerge in a clean fresh water for 28 days. The specimen was removed from water after specified curing time (28 days) and wipe out excess water from the surface, 3 cubes were selected and crushed with the compression testing machine and the crushing load was recorded. A rebound harmer was used to test the hardness of the concrete.

After testing for 28 days strength, some concrete samples were selected and then heated at various time intervals of 30 minutes, 45 minutes and 1 hour to a varying temperature of 100, 150, 200, 250 and 300°C and the same procedure for cube test was carried out to determine the effects of the compressive strength of the concrete. In each case the compressive strength of the concrete was calculated and hardness of the concrete was determining by rebound harmer method to evaluate the effects of temperature on the concrete hardness.

Calculations for Compressive Strength of Concrete

To calculate the compressive strength of the samples, the maximum load was divided by the cross-sectional area (average) of the sample.

- 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 would be 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 was calculated and recorded.

RESULTS AND DISCUSSION

Table 1.1. Compression Test Result

Temperature (0C)	Time (Minutes)	Sample A Load (kN)	Sample B Load (kN)	Sample C Load (kN)	Average Load (kN)
0^0C	00	250.30	252.01	251.38	251.23
100^0C	30	250.30	250.75	250.48	250.51
	45	250.85	250.3	251.38	250.44
	60	251.38	250.85	250.96	250.06
150^0C	30	249.27	247.16	247.69	248.04
	45	248.74	247.69	247.67	248.03
	60	246.11	247.68	246.64	246.81
200^0C	30	247.67	246.11	245.06	246.28
	45	247.16	244.04	242.95	244.72
	60	245.01	245.58	242.95	244.51
250^0C	30	241.89	244.50	243.58	243.32
	45	240.00	240.00	241.50	240.50
	60	238.10	235.00	235.50	236.2
300^0C	30	240.10	241.20	239.50	240.27
	45	235.20	237.60	234.90	235.90
	60	222.39	221.00	220.60	220.60

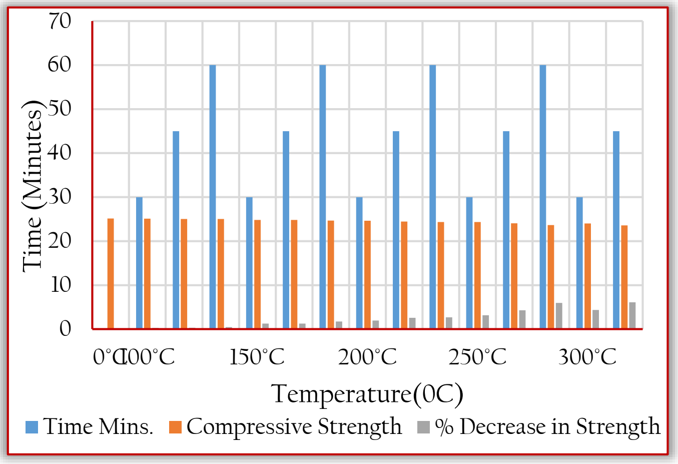

Figure 1.0. Compressive Strength Result at Varying Temperatures and Time with Percentage Decrease.

Table 1.2 Hardness Test Result

Temperatur e (0C)	Time (Minutes)	Sample A	Crushing Sample B	Load kN Sample C	Average
0^0C	00	25.00	25.00	26.00	25.33
100^0C	30	34.00	33.50	33.00	33.50
	45	34.00	33.50	34.50	34.00
	60	35.50	35.00	34.50	35.00
150^0C	30	36.50	37.00	36.50	36.67
	45	37.50	37.00	36.50	37.00
	60	36.50	36.50	37.50	36.83
200^0C	30	35.50	36.50	36.00	36.00
	45	35.50	36.00	35.00	35.50
	60	35.00	35.00	35.50	35.17
250^0C	30	36.50	37.00	36.50	36.83
	45	36.00	36.50	36.00	36.17
	60	35.50	36.50	35.50	35.67
300^0C	30	35.00	35.50	34.60	35.03
	45	34.50	34.50	35.00	34.67
	60	34.00	33.50	33.20	33.57

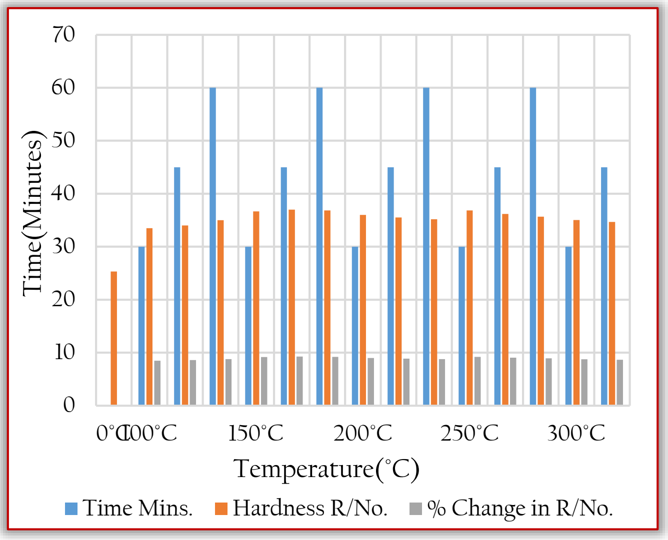

Figure 1.1. Hardness Result with Varying Temperature and Time

Table 1.3. Summary of Results

Temperature ^{0}C	Time Mins.	Compressive Strength	% Decrease in Strength	Hardness R/No.	% Change in R/No.
0^{0}C		25.13	00	25.33	0
100^{0}C	30	25.12	0.29	33.50	8.49
	45	25.05	0.31	34.00	8.61
	60	25.04	0.45	35.00	8.79
150^{0}C	30	24.80	1.27	36.67	9.16
	45	24.80	1.27	37.00	9.25
	60	24.68	1.75	36.83	9.21
200^{0}C	30	24.63	1.97	36.00	9.00
	45	24.47	2.59	35.50	8.87
	60	24.33	2.67	35.17	8.79
250^{0}C	30	24.33	3.15	36.83	9.20
	45	24.05	4.27	36.17	9.04
	60	23.67	5.98	35.67	8.92
300^{0}C	30	24.03	4.36	35.03	8.76
	45	23.59	6.10	34.67	8.67
	60	22.10	12.04	33.57	8.39

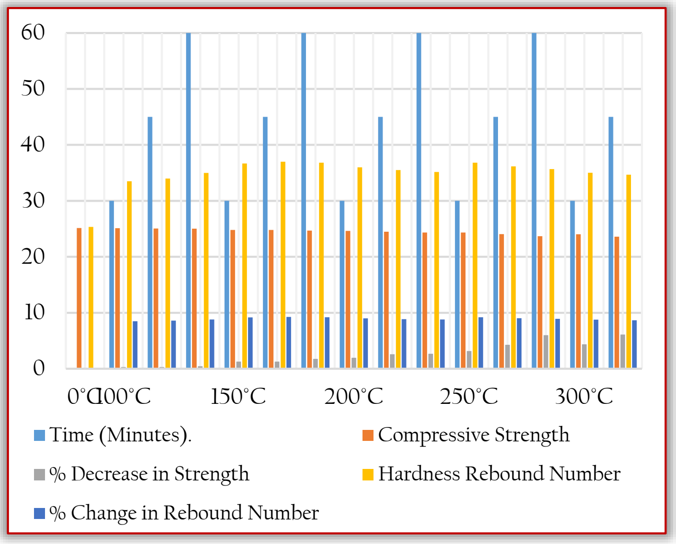

Figure 1.3. Comparative Summary of Compressive Strength and Hardness Results

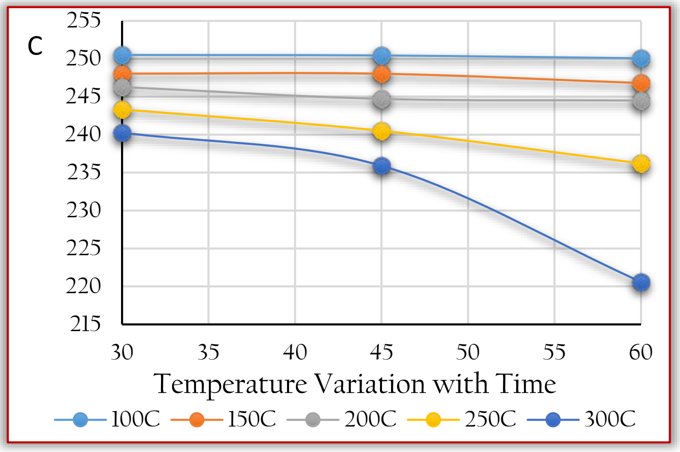

Figure 1.4. Compression Test Graph (Crushing Load Against Time)

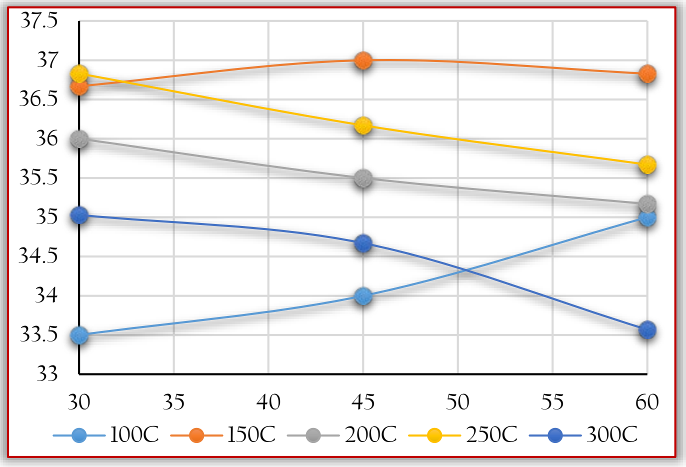

Figure 1.5. Hardness Test Graph (Rebound Number Against Time)

DISCUSSION

From the results above, it was observed the concrete losses it compressive strength with increase in temperature. It was also observed that the maximum loss in compressive strength was 0.45% at 100^{0}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. Normal concrete losses over 20% of its compressive and bond strength at 300^{0}C [2]. This shows that Slag cement has a slight higher resistance to heat attack than Ordinary Portland Cement in terms of both compressive and bond strength. The hardness of concrete was found to be increasing from a temperature of 100^{0}C to 150^{0}C, the peak hardness was observed at 150^{0}C at a heating time of 45 minutes but beyond this, the hardness of the concrete began to drop. This shows that moisture content also has effects on concrete hardness. Between a temperatures of 100^{0}C to 150^{0}C, the effects of temperature were more of drying effects but beyond this point concrete began to lose it hardness.

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. Slag concrete has good workability. 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. Considerable concrete shrinkage is accompanied at this stage. It was noted that at 100^{0}C, the specimen weighed 2437g but 2168g at 300^{0}C.

In the view of [5] the lower strength of the saturated concrete is attributed to the disjoining pressure within the cement paste.

In compression tests it has been observed that air-dried specimens show 20-25% higher strength than corresponding specimens tested in a saturated condition [5]. For an oven-dried specimen, the increase in strength is of the order 10-15%. This increase in strength appears to be reversible as subsequent re-saturation will return the concrete to its original strength at water saturated condition [8]. The effect of moisture content on strength becomes an important consideration when testing drilled cores.

According to [8] 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 cohesion and internal friction using a microscopic scale; a lubricating effect created by moisture causing the slipping of particles more easily in shear. The lesser in the compressive strength of wet concrete is as a result of the internal pore pressure produced by the applied load.

CONCLUSION AND RECOMMENDATIONS

From the results above, it was observed that concrete losses it compressive strength with increase in temperature. It was also observed that the maximum loss in compressive strength was 0.45% at 100°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. It was observed that from a temperature of 100-200°C, there was no significant effects of temperature on the compressive strength of the slag concrete. Above a temperature of 200^{0}C and up to 300^{0}C the effects of temperature on the compressive strength of 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. It was also observed that the time interval at which the concrete was subjected to heat has a significant influence on the concrete strength, the more the concrete stays under heat, the lesser the strength. 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. Furthermore, a manual of structural design for fire safety should be developed for slag cement.

This study has revealed that while concrete mechanical properties are thoroughly researched, there is significant paucity of research with respect to the thermal properties of slag cement concrete at high temperature. It is recommended that more research should be carried out on the thermal properties of slag cement concrete.

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References

[1] E Gartner, Industrially Interesting Approaches to Low-CO2 Cements, Cement and Concrete Research, Elsevier, 2004, 34, 1489-1498.
[2] J Ingham, Application of Petrographic Examination Techniques to the Assessment of Fire-damaged Concrete and Masonry Structures, Mater. Charact, 2018, 60, 700–709.
[3] J Xiao, and G König, Study of Concrete at High Temperature in China—An Overview, Fire Safety Journal, Elsevier, 2004, 39, 89–103.
[4] M Li, C Qain, and W Sun, Mechanical Properties of High-strength Concrete After Fire, Cement and Concrete Research, 2004, 34, 1001–1005, 2004.
[5] PK Mehta, and PM Monteiro, Concrete: Microstructure, properties and materials. Third Edition.Newyork: 2019, McGraw-Hill company Ltd.
[6] R Collins, W Gutt, & A Neville, Discussion: Research on long-term properties of high alumina cement concrete. Magazine of Concrete Research, 1989, 41(149), 243-244
[7] R Mohebi, K Behfarnia, and M Shojaei, Abrasion Resistance of Alkali-activated Slag Concrete Designed by Taguchi Method, Construction and Building Materials, Elsevier, 2015, 98, 792–798.
[8] S Mindess, Resistance of concrete to destructive agencies. Lea's Chemistry of Cement and Concrete, 2019, 251-283
[9] S Ogawa, T Nozaki, K Yamada, H Hirao,, & R Hooton. Improvement on sulfate resistance of blended cement with high alumina slag. Cement and Concrete Research, 2012
[10] W Jau, D Tsay, A study of the basic engineering properties of slag cement concrete and its resistance to seawater corrosion. Cement and Concrete Research, 1998

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