Evaluation of Thermal Effects on Slag Cement Concrete's Strength Properties

Wasiu Ajagbe¹, Sesugh Terlumun², and Michael Tiza^{3,*}

¹Lecturer, Civil Engineering Department, University of Ibadan, Ibadan Nigeria.

²Lecturer, Civil Engineering Department, Air force Institute of Technology, Kaduna, Nigeria.

³Civil Engineer, China Civil Engineering Construction Corporation (CCECC) Nigeria Limited.

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*Thermal strength,
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Abstract

The physical, chemical, and mechanical characteristics of concrete change with heat-fire. The effect of thermal load on Slag cement concrete output must be measured because of the crucial role of thermal resistance in concrete structure performance and operation. This work examines the thermal resistance of Slag cement concrete. The concrete cubes were produced and cured for 28 days and then subjected to varying temperatures range of 100°C, 150°C, 200°C, 250°C, and 300°C. Hardness and compressive strength were measured at 30, 45, and 60 minutes; the sample results were compared to those of ordinary Portland cement used for the study. The findings of this experiment demonstrate that strength loss 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 property increased from 100° to 150°C but decreased with higher temperatures. However, average concrete loss at 300 °C exceeds 20 percent of its compressive strength. This means that higher temperatures have adverse effects on concrete strength. From the test, however, it has been noted that there was an insignificant loss of strength of concrete at temperatures below 250°C and however, above 250 °C, a significant loss of concrete strength was observed. The results indicate that slag concrete has a significantly higher thermal resistance potential than traditional concrete and can be used even in industrial applications.

1. Introduction

Any construction includes certain materials such as steel, brick, mud, clay, glass, stone, wood, and others. Nonetheless, the primary building material used mainly by contractors around the world is cement concrete. Including the emission of CO₂ outflows to the atmosphere, the growing requirement for construction using cement concrete has a natural negative effect [3]. One possible solution is to use Slag Cement Concrete which is given by mixing Ground Blast Granular Furnace Slag (GGBS) with Portland Cement or by extending clinkers to GGBS.

The fire reaction of concrete depends on the mechanical and thermal properties of the concrete and its deformation. Such features differ significantly from temperature to composition, characteristics of the cement batch blend, and heating rate, as well as from other environmental and natural conditions.

Fire is among the most hazardous occurrence a building could have in its lifetime. The efficiency and characteristics of conventional cement concrete at elevated temperatures have been thoroughly investigated [2-3]. Changes in hydration products lead to decreased strength of cement due to chemical and physical alteration of the cement microstructure. The compressive strength of concrete is reduced when the temperature is increased.

The concrete surface reveals fine splits. Up to 300°C fine divisions are observed on the surface of the concrete. Calcium hydroxide (Ca(OH)₂) is also broken down into water and CaO at temperatures above 400°C. As a significant part of cement paste, calcium silicate gel (C-S - H) is disintegrated at 600°C and is the fundamental factor that affects cement consistency.

Concrete completely lost its compressive strength as hydration products degrade at 800°C. The objectives of this research are to examine the thermal properties of blast furnace slag cement at 100, 150°C, 200°C, 250°C, and 300°C. The main mechanical characteristics that assess the reinforced concrete members' fire performance are the stress-strain relationship of essential materials at high temperatures, tensile strength, compressive strength, and elastic modulus.

At high temperatures, compressive concrete strength plays a primary role in fire safety design [4]. Concrete strength depends on aggregates' form and sizes, the mix types, water-cement ratio, the interface of the concrete material, the degree of stress, and the curing conditions at ambient temperature. The binder in the batch mix (fly ash, slag, and silica fume) significantly influences concrete's compressive strength. In contrast, heat rate and room temperature strength are significantly affected by high temperature. Whereas mechanical properties of concrete are extensively studied, cement concrete's thermal properties at elevated temperatures remain considerably lacking. Therefore, it is a research gap to fill.

2. Materials And Methods

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

*Corresponding Author: tizamichzel@gmail.com (Tiza Michael Orcid: 0000-0003-3515-8951)

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2.1 Methods

Preparation of Sample: Slag was obtained from the Prism Steel Company Ikirun. The slag was crushed and grounded into the powdered form, which was used to prepared the binder. By mixing 50% of GGBS with standard Portland cement. On a non-absorbent surface, the fine aggregates and the cement were thoroughly mixed until the mixture was correctly blended to create a uniform color, whereby coarse aggregates were later mixed with cement and fine aggregates until the coarse aggregate was uniformly formed in the batch. Water was then applied with the concrete paste thoroughly mixed in the batch to achieve a homogenous mix with the desired consistency.

2.2 Hardness and Compressive Strength test

Molds were thoroughly cleaned and greased with oil for the removal of formwork, the molds were then filled with concrete in layers with a thickness of 5 cm, and each layer was compacted correctly, using a tamping rod with a minimum of 35 strokes per layer. The test specimens were immersed for 28 days in clear freshwater and then placed in moist air for 24 hours to carry out the procedure. In checking the hardness of the concrete, a rebound harmer was used. After a 28-day strength test, some concrete samples were selected and were subjected to heating at different temperatures of 100°C, 150°C, 200°C, 250°C, and 300°C in various time intervals of 30 minutes, 45 minutes and 1 hour. The same cube test method was used to assess the effect of a concrete's compressive strength. For each case, the compressive strength of the concrete was measured and the hardness of the concrete was determined by the rebound harmer test method, to assess temperature effects on the hardness properties of the concrete.

Table 1. Compression Test Result

Temperature (°C)	Time (Minutes)	Sample A Load (kN)	Sample B Load (kN)	Sample C Load (kN)	Average Load (kN)
0	00	250.30	252.01	251.38	251.23
100	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	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	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	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	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. Compressive Strength Result at Varying Temperatures and Time with Percentage Decrease

Table 2. Hardness Test Result

Temperature (°C)	Time(Minutes)	Sample A	Crushing Sample B	Load kN Sample C	Average
0°C	00	25.00	25.00	26.00	25.33
100°C	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°C	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°C	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°C	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°C	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 2. Hardness Result with Varying Temperature and Time

Figure 3. Comparative Summary of Compressive Strength and Hardness Results

Figure 4. Compression Test Graph (Crushing Load Against Time)

Figure 5. Hardness Test Graph (Rebound Number Against Time)

3. Results and Discussion

The maximum drop in the compressive strength was 0.45% at 100 °C, 1.75% at 150°C, 2.67% at 200 °C, 5.98% at 2500 °C and 12.04% at 300 °C. Average concrete losses at 300°C over 20% of their compressive and bonding strength [2]. The above indicates that the strength of the slag cement in terms of compression and bond strength is a bit higher than the ordinary Portland cement.

The hardness of concrete was found to be increasing from a temperature of 100°C to 150°C, the peak hardness was observed at

150°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 temperature of 100°C to 150°C, the temperature results were more of drying effects, but beyond this point, concrete began to lose its hardness.

Higher temperatures exert adverse effects on cement concrete strength. The slag cement's compressive strength was considerably higher than Portland cement, as other researchers already established. Slag concrete has good workability. As the concrete is slowly heated, weight loss tends to happen in two phases: the drying

phase, water evaporation from large voids and capillaries. The loss of non-evaporated water from gel pores and small capillary pores may occur in the dehydration stage. It was noted that at 100°C, the specimen weighed 2437g but 2168g at 300°C.

Compression experiments have shown that air-dried specimens are 20-25 percent stronger than the corresponding saturated samples [5]. The intensity increase for an oven-dried specimen amounts to 10-15%. This rise in strength seems reversible, as the re-saturation returns the concrete to its original strength in a water-saturated state [8]. When testing drilled cores, the effect of moisture content on strength is significant.

Following [8], the alteration of the C-S-H structure during drying may be related or merely represent a shift in internal friction and cohesion using a microscopic scale; a lubricant effect produced by moisture that makes it easier to slip particles in shear. As a result of internal pore pressure from the applied load, the less compressive strength of wet concrete is produced. From the results above, it was witnessed that there was a loss of compressive strength of concrete with an increase in temperature. It was also identified that the concrete's maximum loss in compressive 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.

From the results above, it was witnessed that there was a loss of compressive strength of concrete with an increase in temperature. It was also identified that the concrete's maximum loss in compressive 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. It was also observed that from a temperature of 100-200°C, there was no significant temperature effect on the slag concrete's compressive strength.

4. Conclusion and Recommendations

A loss of the compressive strength of concrete and a temperature rise was observed from the above findings. The compressive strength's loss for the concrete was also found to be 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. Therefore, there were no significant temperature effects from 100-200°C on the slag cement concrete.

Above a temperature of 200°C and up to 300°C, the temperature effect on the concrete's compressive strength became significant. At 250°C (5.98%) at 60 minutes but was still not effective at 30 and 45 minutes (3.15-4.27%), but at 300°C, a significant 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 was observed to affect the strength of concrete significantly. The more the concrete stays under heat, the lesser the strength. Slag Cement concrete has slightly higher but approximately the same thermal resistance ability compared to ordinary Portland cement.

A loss of the compressive strength of concrete and a temperature rise was observed from the above findings. The compressive strength loss for the concrete was also found to be 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. Therefore, there were no major temperature effects from 100-200°C on the slag cement concrete.

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 revealed that while mechanical characteristics of the concrete are investigated, considerable work is required concerning high-temperature slag concrete's thermal features. More work on the thermal characteristics of the slag cement concrete is recommended. Mathematical models can as well be considered for the future scope of this work.

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Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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