EFFECTS OF TEMPERATURE VARIATION ON THE BOND AND TENSILE STRENGTH OF SLAG CEMENT CONCRETE

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Abstract

This work examine the effects of thermal variance on the split tensile strength of slag cement concrete. In this research, slag cement was prepared by blending 50% Portland cement with Ground Granular Blast Furnace Slag and used as the binder. Concrete cylinders of 100mmx300mm were prepared using slag cement, the samples were cured for 28 days to achieve strenght. Therafter, some samples were selected and tested to determine the tesile strength using split tensile test while some were subjected to varying thermal conditions of 150, 200, 250 and 300C at time intervals of 30, 45 and 60 minutes after which split tensile test was conducted on the heated samples to determine effects of varying temperature conditions. At the end of the research, it was observed that slag cement concrete has good thermal performance compare to ordinary Portland cement

Keywords: Temperature, Variation, Bond, Tensile Strength, Slag Cement Concrete

INTRODUCTION

Cement has been considered the most expensive constituent of concrete materials. As a result, when used in chemically aggressive environments, the chemical composition of the environment reacts with that of the cement, causing changes in the chemical composition of the cement, reducing the strength and durability of the structure. Attempt to get or convert a suitable waste to effectively replace or minimize the use of Portland cement, and appreciably reduce the cost of construction and produce concrete with better resistance to chemical attack, ground granular blast furnace slag has been found to be suitable. Concrete produced with ground granular blast furnace slag cement is superior to that of ordinary Portland cement in terms of strength, durability, and better workability. However, there is a grave need to assess the thermal resistance ability of slag cement. Hence, this work examined the response of slag cement concrete to heat or fire attack.

This work will be of great use to the construction industry in the following ways:

1 To help in providing a guide for structural engineers in designing for fire safety when using ground granular blast furnace slag cement.
2 To help in deciding certain areas and industrial conditions in which slag cement can be effectively use.
3 Civil engineering agencies and researchers will benefit from this work serving as a reference document or basis for further research.

It is impossible to overstate the importance of concrete in practically every aspect of civil engineering and building construction. There are three ingredients in concrete: cement (fine and coarse), water, and aggregates [1]. These three ingredients are combined in a precise ratio to provide the desired strength. Together with water, a paste is formed that holds the aggregate together. This paste is made via a chemical reaction [1]. There is excellent compressive strength but minimal resistance to tension in the rock-like solid mass formed by the combination. Cement, granite, and sand are the most common ingredients used to make concrete in the building business. In developing nations, the high and rising cost of these materials has stifled the construction of housing and other infrastructure facilities [2;3]. The building industry relies heavily on raw materials as the world's infrastructure grows [4]. The demand for raw materials rises due to an increase in the amount of material used. Many have been troubled by the rising worry about global pollution and the loss of natural resources [4].

Concrete strength is commonly considered as most valuable property especially in designing and quality control and other practical situations [5]. However, other characteristics such as permeability, durability may be of more value in assessing concrete performance, strength produces a general feature of concrete quality and is a vital element considered in design of structures and is specified for compliance purposes [6]. The ratio of flexural and compressive strength depends on the grade of concrete, it mostly varies from 0.01 to 0.02 for strong and weak concrete [7]. Compressive strength determination in concrete is of more value owing to the fact that the primary function of concrete is to withstand compressive stresses. Compressive strength usually gives an idea of the shear or tension strength of concrete [8].

The strength of concrete is a function of the mortar strength, the bond between the coarse aggregates and the mortar and the aggregates strength to resist applied stresses [9]. The flexural and compressive strength of concrete relationship depends on the type of coarse aggregates, most especially; the shape and surface texture of the aggregates affects the ultimate strength in compression much lesser than in tension. High aggregates contents in concrete enhances lower bleeding, shrinkage and damages to aggregates and cement bond and thermal effects due to heat of hydration is lowered. Concrete is a durable material which requires little or no maintenance. This is very true except when placed in aggressive environment, so the extent of harshness of the environment which concrete is serving affects the durability of concrete and as a matter of fact, both strength and durability of concrete should be given prior attention at the design stage [10].

In designing of concrete structures, the exposure condition and thermal action should be considered, in terms of foundations, soil characteristics should also be investigated properly [11;12]. Environmental pollution is Increasing daily most especially in industrial atmosphere and urban areas. Even though cement production is being modernized frequently but, in some cases, second grades low materials for example limestone containing excess chloride are used for certain economic reasons.

[13] in their research noticed that there was gradual reduction in the compressive strength of concrete immersed in acids solutions, the higher the concentration the lesser the compressive strength. It was discovered from their research that sulphuric acid was found to be more aggressive to concrete than hydrochloric acid, while hydrochloric acid was found to be more aggressive than nitrate acid. Hence, degree of reduction of the compressive strength was found to depend on the type of acid, it concentration and the duration of concrete in the aggressive media. After using about three different grades of concrete, it was observed that the grade of concrete has no appreciable influence on the it resistance to the aggressive media which agrees with the findings of various researchers [14].

Since it has been established from various researchers that these acids exert a deleterious effect on the chemical properties of concrete which retard the compressive strength of the concrete [14], this research is aimed at minimizing these effects to achieve and maintain a more reasonable strength for structures constructed in such aggressive environmental conditions. 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[15].

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.

Fire Resistance

To put it another way, fire resistance measures how long a building can withstand temperature transmission, structural integrity, and stability while being exposed to a fire of a certain intensity without collapsing or failing in any other way. When building structures for safety, the first and most crucial step is to ensure that the structure's fire resistance is higher than the fire's intensity [15].

Many important factors, such as load level, fire scenario, and concrete strength, are not included in the prescriptive techniques for fire resistance that are based on data from regular fire resistance tests [16].

Discolorations and tarnish induced by smoke may be seen on a concrete structure, as can the destruction of a structural member due to the loss of mechanical strength [17]. Buildings' ability to resist fire growth directly impacts the impacts of fire, including its severity and spread. Preventive measures are taken to reduce the danger of fires, but unfortunately, there is no absolute protection. Concrete must be able to withstand the impacts of intentionally created high temperatures, such as near furnaces or atomic reactors, on pavements subjected to jet engine blasts, and in regions exposed to fire. Certain applications of high-temperature concrete are regarded as disposable, but in most cases, it is intended to minimize the degradation of the concrete's physical attributes [17].

There are several variables to consider when deciding what kind of concrete to use in a high-temperature situation. Longevity, temperature increase, temperature to which concrete mass is subjected, concrete's temperature at the start of exposure to high temperatures, concrete's saturation level with water at the time of exposure, aggregate/cement ratio, and loading circumstances are factors [18]. When subjected to 400 degrees Fahrenheit, concrete seems to be unaffected. There should be some investigation into the exposure circumstances and the concrete used when temperatures exceed 400 degrees Fahrenheit. A structural member's resistance to deterioration in structural stability, rigidity, and temperature transfer is quantified in terms of fire resistance, a property of fire safety measures applied to structural members. Generally speaking, concrete is the most fire-resistant construction material. Because concrete's component ingredients (i.e., cement and aggregates), when chemically mixed, make a virtually inert material and have poor thermal conductivity, high-temperature capacity, and slower strength deterioration with temperature, this excellent fire resistance may be attributed to it [18].

To prevent fire damage and restrict the spread of flames inside a building, concrete uses its poor thermal conductivity and high thermal mass. Fire-resistant qualities of the concrete from which a structural member is made have a significant role in the member's performance in a fire. The mechanical, thermophysical, and deformation characteristics of concrete are very different from other materials when they're at the same temperature as a fire in a building. In addition to temperature, these qualities are influenced by the composition and features of concrete. The strength of concrete influences both room temperature and high-temperature characteristics. With temperature, the characteristics of HSC change from those of normal-strength concrete (NSC) [18].

Mechanics are more likely to change than other variables. This change affects things like moisture content and strength as well as things like density, the amount of silica fume and porosity.

Standard fire tests are the primary method of evaluating structural elements for fire resistance in the real world. Structural members are increasingly being calculated using a numerical technique since it is less expensive and time-consuming than the traditional method. It is possible to forecast the temperature profile of a structural member that is exposed to a specific temperature-time exposure during a fire. The materials that make up a structural member distort and alter properties when exposed to higher temperatures. In order to anticipate a structural member's fire-resistance performance, the conventional techniques of structural mechanics may be utilized. Material attributes must be available at a higher temperature to anticipate structural members' fire resistance.

Tensile Strength

Observations from flexural and split cylinder tests are used in most reinforced concrete research studies to directly determine composites' tensile characteristics. This is because direct tension testing provides data that is difficult to interpret. Specimen sizes, specimen morphology, apparatus, and measuring methods are all factors that contribute to challenges in the study. For direct tension testing, there is currently no standard test specimen [19]. Thus, the observed stress-strain curve or the force-elongation curve under direct tension is predicted to vary depending on the specimen size, the stiffness of the testing equipment, the gauge length used to compute strains, and the number of fractured fractures generated within the gauge length. Consequently, tensile reaction in reinforced concrete composites may be difficult to characterize since post-cracking behavior tends to be dominated by the widening of one large fracture, which has been documented in various experimental experiments [20].

The concentration of deformations at fracture sites results in a non-uniform definition of strains in the cracked area, dependent on the required gauge length. This elastic material may be comparable to a non-uniform matrix before cracking, and the stress-strain response is highly similar. There are fewer experiments on reinforced concrete's splitting tensile strength than there are on its direct tension, flexure, and compression strengths. As with direct tension, flexure, and compression tests, elements affecting reinforced concrete's performance should also influence its split tensile behavior. These include fibre volume fraction, aspect ratio, and bond strength characteristics. In order to raise the splitting tensile strength of fibre composites, one may increase the volume fraction of fibres and increase their aspect ratio. In addition, compared to straight or non-deformed bars, hooked and deformed fibres are projected to provide better splitting tensile resistance.

Bond Strength

The ability of concrete reinforcement to increase a section's tensile strength is directly related to the compatibility of the two materials used to withstand an external load [21]. There must be an equal amount of strain or deformation on both the reinforcement element and the surrounding concrete to ensure they do not become separated or discontinuous under load. For a reinforced concrete section to be effective, the modulus of elasticity, ductility, and yield strength of the reinforcement must be much greater than the concrete. The link or adhesion required between the reinforcement and concrete cannot be developed using brass, Aluminium, rubber, or bamboo materials (22). They have the requisite properties: yield strength, ductility, and bonding value. As the concrete hardens, it exerts pressure on the steel bar or wire due to its drying shrinkage [23;24]. This results in a combination of factors that contribute to bond strength. An additional benefit of the tensioned bar micro-movements is the higher friction interlock between bar surface deformations or projections and concrete. Bond is the collective consequence of all of this.

MATERIALS AND METHODS

Materials

Steel slag: Blast furnace slag 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: The binder used for this research was prepared by blending 50% of the Granulated Ground Granular Blast Furnace Slags with ordinary Portland Cement. 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

Fine 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.

Coarse aggregates: The coarse aggregates used for this research is granite. The aggregates sizes were 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 portable. It conforms to the requirements of BS EN 1008:2002 requirements.

(a) (b)

(c) (d)

Figure 1: Compression Test Samples

Figure 2: Compression Test Machine used in the experiment Cylinder Sample

Figure 3: Split Tensile Cylinder Samples after Failure

RESULTS AND DISCUSSION

Split Tensile Test Result

Table 1 below shows the result of the split tensile test of the slag cement concrete at various temperatures and time

Table 1. The result of the split tensile test of the slag cement concrete at various temperatures and time

Temperature (^{0}C)	Time(Minutes)	Average Load (kN)
0^{0}C		38.50
100^{0}C	30	38.24
	45	38.22
	60	38.05
150^{0}C	30	38.06
	45	37.94
	60	37.88
200^{0}C	30	37.54
	45	37.03
	60	36.78

250^{0}C	30	36.48
	45	35.11
	60	34.18
300^{0}C	30	34.04
	45	32.15
	60	31.38

Pull out Test Result

Table 2 below shows the result of the pull-out test carried out on the slag cement concrete under varying temperatures and time

Table 2: The result of the pull-out test.

Temperature (^{0}C)	Time(Minutes)	Average Load (kN)
0^{0}C		45.76
100^{0}C	30	45.64
	45	45.49
	60	45.44
150^{0}C	30	45.41
	45	45.32
	60	45.28
200^{0}C	30	45.25
	45	45.08
	60	44.63
250^{0}C	30	44.05
	45	42.93
	60	41.32
300^{0}C	30	39.08
	45	37.14
	60	36.76

From the result above, the tensile strength of the slag concrete can be calculated below

Tensile Strength = 2P/ΠDL

Where P is the crushing load, D is the diameter of the cylinder and L is the length of the cylinder

At 0^{0}C

Tensile Strength =2P/ΠDL = 2x38.60x10^3/3.14x100x200 = 1.2293N/mm^2

100^{0}C at 30 minutes = 2x38.23x10^3/3.14x100x200 = 1.2175 N/mm^2

At 45 minutes = 2x38.20x10^3/3.14x100x200 = 1.2166 N/mm^2

At 60 minutes = $2x38,03x10^3/3.14x100x200 = 1.2111$ N/mm^2

150^0C at 30 minutes = $2x38.03x10^3/3.14x100x200 = 1.2111$ N/mm^2

At 45 minutes = $2x37.90x10^3/3.14x100x200 = 1.2070$ N/mm^2

At 60 minutes = $2x37.85x10^3/3.14x100x200 = 1.2054$ N/mm^2

200^0C at 30 minutes = $2x37.50x10^3/3.14x100x200 = 1.1943$ N/mm^2

At 45 minutes = $2x37.00x10^3/3.14x100x200 = 1.1783$ N/mm^2

At 60 minutes = $2x36.79x10^3/3.14x100x200 = 1.1717$ N/mm^2

250^0C at 30 minutes = $2x36.47x10^3/3.14x100x200 = 1.1615$ N/mm^2

At 45 minutes = $2x35.10x10^3/3.14x100x200 = 1.1178$ N/mm^2

At 60 minutes = $2x34.17x10^3/3.14x100x200 = 1.0882$ N/mm^2

300^0C at 30 minutes = $2x34.03x10^3/3.14x100x200 = 1.08375$ N/mm^2

At 45 minutes = $2x32.13x10^3/3.14x100x200 = 1.0232$ N/mm^2

At 60 minutes = $2x31.37x10^3/3.14x100x200 = 0.9990$ N/mm^2

From the result above, the bond stress of the concrete can be calculated as follows:

Stress (σ) = Load (P)/Area (A)

The embedded area A = ΠDL

So σ = P/ΠDL

At 0^0C σ = P/A = $45.75x10^3/3.14x10x10x10 = 14.57$N/mm^2

100^0C at 30 minutes = $45.63x10^3/3.14x10x10x10 = 14.53$ N/mm^2

At 45 minutes = $45.48x10^3/3.14x10x10x10 = 14.48$ N/mm^2

At 60 minutes = $45.42x10^3/3.14x10x10x10 = 14.46$ N/mm^2

150^0C at 30 minutes = $45.42x10^3/3.14x10x10x10 = 14.46$ N/mm^2

At 45 minutes = $45.30x10^3/3.14x10x10x10 = 14.43$ N/mm^2

At 60 minutes = $45.27x10^3/3.14x10x10x10 =14.41$ N/mm^2

200^0C at 30 minutes = $45.24x10^3/3.14x10x10x10 = 14.41$ N/mm^2

At 45 minutes = $45.06x10^3/3.14x10x10x10 = 14.35$ N/mm^2

At 60 minutes = $44.61x10^3/3.14x10x10x10 = 14.21$ N/mm^2

250^0C at 30 minutes = $44.04x10^3/3.14x10x10x10 = 14.03$

At 45 minutes = $42.90x10^3/3.14x10x10x10 = 13.68$ N/mm^2

At 60 minutes = $41.31x10^3/3.14x10x10x10 = 13.16$ N/mm^2

300^0C at 30 minutes = $39.09x10^3/3.14x10x10x10 = 12.45$ N/mm^2

At 45 minutes = $37.11x10^3/3.14x10x10x10 = 11.82$ N/mm^2

At 60 minutes= $36.75x10^3/3.14x10x10x10 = 11.70$ N/mm

The data above shows that concrete loses its tensile and bond strength as temperatures rise. 1.48 per cent at 100oC, 1.94 per cent at 1500C, 4.69 per cent at 2500C, 11.8 per cent at 3000C and 18.73 per cent at 3000C were found to have the most significant tensile strength loss. Standard Strength Concrete loses roughly 20% of its tensile strength at temperatures of

300°C. This study validates that slag concrete has a somewhat stronger tensile heat resistance than conventional concrete. It is usual for concrete to lose more than 20% of its compressive and bond strength when heated to 300^0 degrees Celsius. The maximum bond strength loss was 0.72 per cent at 100 degrees, 1.05 per cent at 150^0 Celsius, 2.49 per cent at 200^0 Celsius, 9.7 per cent at 250^0 Celsius, and 19.67 per cent at 300^0 Celsius. Regarding compressive and bond strength, slag cement has a significant advantage over OPC. The strength of concrete is reduced as the temperature rises above 90 degrees Fahrenheit. It was previously shown that the compressive strength of slag-cement concrete was much greater than that of Portland cement. Concrete made from slag is straightforward to deal with. Two phases of weight loss occur when concrete is heated gradually: the drying stage and water evaporation from big capillaries and voids. When the gel pores and tiny capillary holes are dehydrated, the loss of non-evaporated water from these pores will occur. There is much concrete shrinkage in this 20th stage. The specimen weighed 2437g at 100^0C but only 2168g at 300^0C. According to [25], the dilation of the cement gel by water-adsorbed water results in a reduction in the forces of cohesion between the solid particles. The specimen's apparent strength increases when the wedge-action of water is stopped during drying.

CONCLUSION

From this research, the following conclusions were made:

1 Slag cement concrete has a considerable higher compressive strength than Ordinary Portland cement.

2 It was observed that from a temperature of 100-200^0C, there was no significant effects of temperature on the mechanical properties of the slag concrete. Compressive strength was (0.29-2.67), tensile strength was (0.96-4.69%), bond strength was (0.26-2.49%) which may be negligible.

3 Above a temperature of 200^0C and up to 300^0C the effects of temperature on the compressive concrete became significance. At 250^0C (5.98%) at 60 minutes but was still not significance at 30 and 45 minutes (3.15-4.27%), but at 300^0C, a significance effect was noticed from 45 minutes to be 6.10%. For tensile strength, The higher the temperature, the lesser the compressive strength.

4 It was also observed that 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.

5 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.

RECOMMENDATIONS

The following recommendations were made:

1. Higher temperature values should be use to examine much of the effects of temperature on the strength and properties of concrete.

2. Other mechanical properties like, flexural strength, fracture toughness e.t.c. should also be investigated to properly examine the performance of slag cement on thermal conditions.
3. Much work should be done to bring out a balance design of slag cement for fire safety.
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.

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