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Correlating Experimental and Predictive Method for Compressive Strength of Concrete with Temperature Effects

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Abstract: *This study assessed the effects of elevated temperature on the compressive strength of concrete to determine the strength of concrete after fire outbreak. Two assessments were done which include; using laboratory experimental tests and using a mathematical model. The concrete grade of 25N/mm^2 with design mix of 1:1.5:3 and w/c of 0.56 were used. A total of 21 concrete cubes (150mm x 150mm x150mm) were cast. After 24hrs, the cubes were de-moulded and cured in water at ambient temperature in the laboratory for 28 days. At 28 days age, the cubes were removed from the curing tank and air-dried for 2hrs before being subjected to these sustained elevated temperatures: 28^{o}C, 50^{o}C, 100^{o}C, 150^{o}C, 200^{o}C, 300^{o}C and 400^{o}C for 1 hour. Thereafter their compressive strengths were determined. A Non-linear regression model was developed to predict the compressive strength of the cubic concrete specimen after oven heating. The model adequately predicted the compressive strength of concrete at given temperatures and weight after oven heating with a correlation coefficient of 0.81.*

Key words: *Concrete, Temperature, Compressive strength, Non-Linear Model,*

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I. Introduction

Concrete is known for its ability to withstand elevated temperature because of its low thermal conductivity. It is a material widely used in construction of both low and high rise buildings as well as for special purposes. Concrete properties and concrete response to the influencing factors, such as loading, temperature and moisture depend on the properties of the concrete constituents. It can be said that the concrete microstructure derives its macro properties through the combined properties of different aggregate types and the cement paste (Cement Concrete and Aggregate Australia [1]. According to CCAA [1], the four main properties of concrete are workability, cohesiveness, strength and durability. The workability of concrete enables the material components to be compacted into forms having any reasonable shape while durability ensures a long life for the hardened mass of the concrete. During hydration and hardening, concrete develops certain physical and chemical properties. The mechanical strength and durability are considered to have an important role in the design process. Thermal properties of concrete are also an important aspect while dealing with durability of concrete.

The study of thermal behaviour of concrete in different situations forms an important topic while dealing with durability of concrete in the thermal conductivity of the concrete, coefficient of thermal expansion and fire resistance. The effect of elevated temperatures on certain mechanical and physical properties of concrete may determine whether the concrete will maintain its structural integrity or not. Concretes are good in compression and give the best fire resistance among other building materials; hence concrete has the ability to protect itself from fire damage [2]. This does not mean that high temperature does not affect concrete as the compressive strength, density, surface appearance are affected [3] as the bond between the cement and aggregates are destroyed [4]. Concrete compressive strength is a measure used in designing concrete structures performance [5].

Concrete structures sometimes are exposed to high temperatures than the normal temperature that it was made. This can be from accidental building fires, jet aircraft engine blast, etc. When exposed to temperatures other than the ambient one, the properties of the concrete (chemical and physical) changes as a result of the elevated temperature [6]. There is loss in the compressive strength of concrete [7] and it also lead to spalling and cracks in buildings [8, 6]. Aggregate type and the strength of concrete at room temperature, influences the loss in strength of concrete and high temperature has negative impacts on the strength of concrete, disturbs its properties and concrete long term strength is reduced [9]. Most design codes gives specifications for the safety of structures at this temperature [10]. The behaviour of concrete structural member exposed to fire depends on its thermal properties to determine the extent of heat transfer on the structure, mechanical properties for the strength loss and stiffness of the structure. It also depends on the deformation which determine the extent of strains and deformation in the structure [6]. In reinforced concrete designs, nominal cover for fire resistance are measures necessary to reduce risks of spalling and cracking on structures as these risks may cause loss of structural integration leading to shortening of its intended life. The suitability of design concrete cover is important to protecting the reinforcement. High temperature properties of concrete are crucial for modelling fire resistance of reinforced concrete structures [2]. It is then of great importance for practical application.

Many times, the experimental results vary greatly with model results. The errors can be from human, machines and apparatus, processing the materials, etc, that may not be intentional. These errors are sometimes much that the entire experimental processes need to be repeated, hence the need for a model method that can predict the concrete strength with very minimal or no error. This paper presents the elevated temperature effects for the laboratory and model results on concrete and its ability to serve its intended use. This will reduce damage to human lives and properties.

II. Materials

Unicem Ordinary Portland Cement; the Fine Aggregates were gotten from Nyama River in Enugu State Nigeria and it has finess modulus of 2.3; Crushed Coarse Aggregates are from Abakiliki, Ebonyi State Nigeria with maximum aggregate size of 20mm well graded and it has specific gravity of 2.67; Good water supply.

2.1 Methods

2.1.1 Laboratory

The laboratory tests performed on these materials include; particle size distribution for the aggregates, specific gravity, slump test, compressive strength etc. Design parameters gotten from these tests gave a mix design of ratio 1:1.5:3 and w/c of 0.56 used. The concrete cubes were cast, de- moulded after 24 hours and cured at room temperature for 28 days continuously.

At 28 days expiration, the cubes were removed from curing tank, placed on a clean surface and allowed to air dry for 2 hours at room temperature. After 2 hours, the cubes were placed in the oven at these sustained temperatures; 28^{o}C, 50^{o}C, 100^{o}C, 150^{o}C, 200^{o}C, 300^{o}C and 400^{o}C for 1 hour each. A total of 21 concrete cubes were made, three samples for each temperature. The cube weight before and after oven were recorded. After oven heating, the samples were cooled in air for 2 hours and their compressive strengths determined.

2.1.2 Model

Non-linear regression model was developed to predict the compressive strength of the cubic concrete specimen after oven heating. The independent variables are the weight of the specimen and its temperature, while the dependent variable is the compressive strength after subjecting it to heat with the equation;

$$F = a_0 W^{a_1} T^{a_2} \quad (1)$$

Where F is the concrete compressive strength (N/mm^2), T is the temperature (^{0}C), W is the weight of the cubic specimens after oven heating (Kg), and a_0 , a_1 and a_2 are the constants. Applying natural logarithm on both sides of Eq. (1) we obtain;

$$lnF = lna_0 + a_1 lnW + a_2 lnT \quad (2)$$

$$lnF \equiv y, lna_0 \equiv a, a_1 \equiv b, lnW \equiv x_1, a_2 \equiv c, lnT \equiv x_2$$

$$y = a + bx_1 + cx_2 \quad (3)$$

Through calibration using the laboratory observed data, the constants a_0 , a_1 and a_2 were determined resulting to Eq. (4);

$$F = 0.0492W^{3.2536}T^{-0.1169} \quad (4)$$

The values for the compressive strength of concrete using the model equation (4) were determined and presented in Table 2

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III. Laboratory Results

Table 1: showing the laboratory cube results before and after oven heating.

Temperature	Average Cube weight before oven (kg)	Average Cube weight after oven (kg)	Average Percentage weight loss	Average Cube Density	Average Failure load (kN)	Average Compressive Strength (N/mm^2)
Room temp (25^o)	8.66	8.66	0	2570.27	780.00	34.67
50^{o}C	8.66	8.66	0	2570.27	780.00	34.67
100^{o}C	8.59	8.51	0.93	2545.68	698.33	31.04
150^{o}C	8.63	8.46	1.97	2510.13	849.10	37.74
200^{o}C	8.62	8.41	2.44	2492.64	611.66	27.19

300°C	8.61	8.21	4.65	2452.20	501.66	22.29
400°C	8.56	8.00	6.54	2368.04	416.70	18.52

3.1. The Model results;

Table 2: Result of Model Compressive Strength at various temperatures

Temperature (°C)	Compressive Strength (N/mm^2)
25	37.92
50	34.97
100	30.46
150	28.50
200	27.03
300	23.84
400	21.19

Table 3: Showing the laboratory and model strength values

Temperature (°C)	Laboratory Compressive Strength (N/mm^2)	Model Compressive Strength (N/mm^2)	Difference in Strength (N/mm^2)
25	34.67	37.92	-3.25
50	34.67	34.97	-0.30
100	31.04	30.46	0.58
150	37.74	28.50	9.24
200	27.19	27.03	0.16
300	22.29	23.84	-1.55
400	18.52	21.19	-2.67

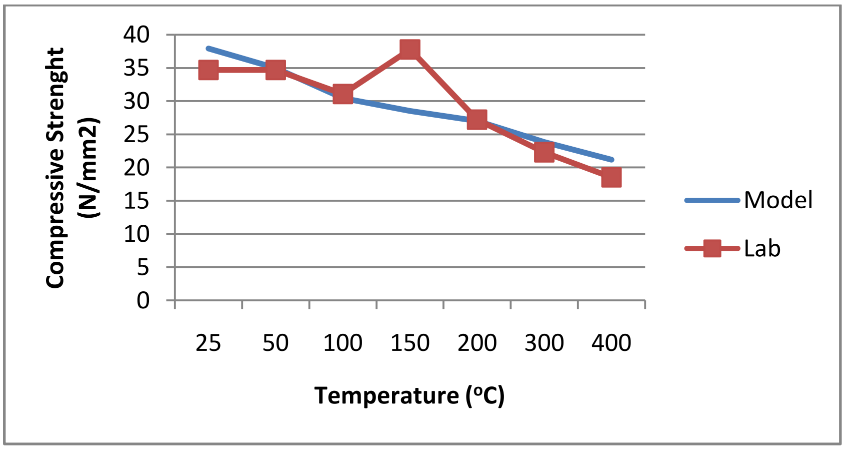

Fig.1: Compressive Strength Result of the Laboratory and Model

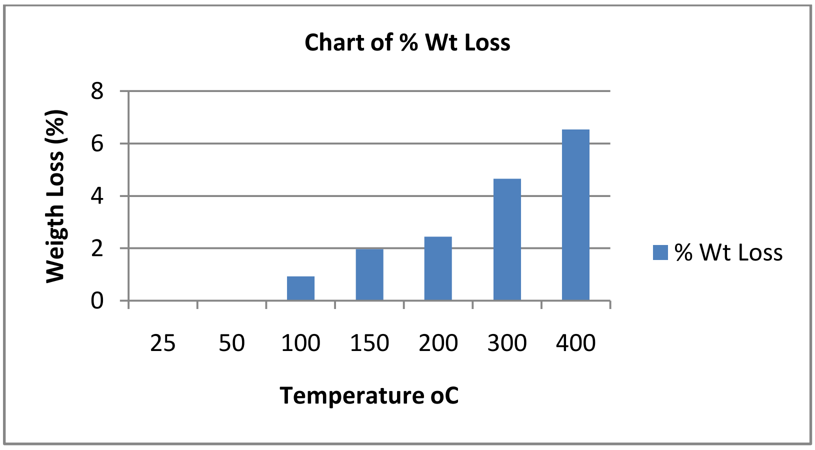

Fig.2: Chart showing concrete loss in weight as Temperature increases from the laboratory.

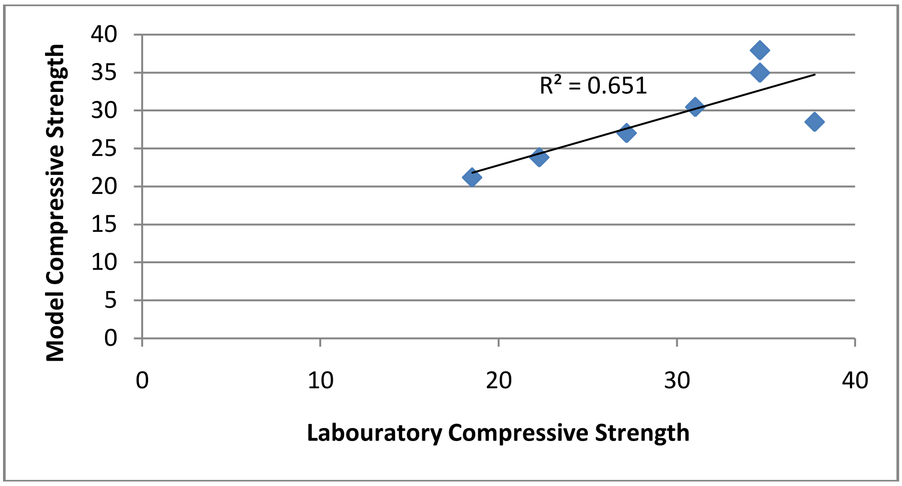

Fig.3: Coefficient of determination of laboratory and model compressive strength of concrete

IV. Discussion of Result

The loss of moisture content in concrete from elevated temperature reduces the weight and density of concrete as temperature increases. This was shown in Table1. It is evident that outside the ambient temperature, the concrete compressive strength, its density decreases as temperature increases. This is not good for concrete structures in case of fire outbreak as it will affect the structural integration (a result of the destruction of the bond between the cement and the aggregates) by causing cracks, spalling, and eventual collapse of the structure.
From this investigation, in Fig.1 and Table 3, the strength of concrete from the model gave a clear cut result than the laboratory. This explains elimination of any error be it human, machines or from the processes involved by using model analysis. The more the structure is exposed to elevated temperature, the greater damage it experiences. Depending on the intensity of elevated temperature, concrete structures of these composition make-ups with compressive strength 25N/mm^2 at 300^{o}C can be renovated and still serve its intended purpose from table 3. Fig.3 shows the coefficient of determination (R^2) which is used to know the correlation between the laboratory data and the model predicted data. The value R^2 = 0.651is a reliable indication that the model adequately the experimental data with the correlation coefficient of 0.81 also.

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