TEMPERATURE EFFECTS ON GRADE 30 CONCRETE USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

This work tends to investigate the effects of mild temperature variations on the compressive strength of grade 30 concrete using response surface methodology. An experimental research design was adopted, which produced ninety (90) concrete specimens. The specimens were exposed to temperatures of 25°C, 62.5°C, and 100°C for one (1) hour in an electric furnace, after 28 days of curing. The optimum results show 11.8% and 12.1% increase of concrete compressive strength at 62.5°C and 100°C when compared to the control's compressive strength at 28 days curing duration. The adjusted coefficient of determination (R^2) was 0.1630 which means that the independent variable was able to explain 16.30% of the residual compressive strength variation in the linear model.

Keywords: compressive strength, concrete grade, curing duration, temperature
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INTRODUCTION

Concrete as a non-combustible material does not contribute to the fire load but acts as a barrier to the spread of fire for one-hour period [1]. Under normal conditions, most concrete structures are subjected to a range of temperature no more severe than that imposed by ambient environmental conditions. However, there are some scenarios where these concrete structures may be exposed to much higher temperatures like building fire, metallurgical and chemical industrial application [2].

Some researchers have studied the effect of the strength grade of concrete, cement and aggregate on the strength of concrete exposed to high temperature [3, 4, 5, 6]. The work done by Umasabor [7] studied the evaluation of temperature effects on grade 20 concrete using response surface methodology. He reported that grade 20 concrete percentages losses were negligible when exposed to 20ºC and 120ºC temperatures accordingly. The work done by Ichise *et al.* [5] discussed the mechanical properties of six kinds of high-strength concretes under high temperatures, and pointed that the compressive strength of concrete with 25 % - 50% of water binder declined from 200ºC, and dropped to 30 - 40% of its normal strength at 600ºC.

Husem [3] examined the influence of cooling methods on the compressive strength, and concluded that the decrease of compressive strength is greater when cooled in water, compared to in the air. Toumi *et al.* [8] studied Coupled Effect of High Temperature on Heating Time on the Residual Strength of Normal and High-Strength Concrete. They found out that the residual strength of concrete decreases as the exposure temperature increases and prolonging the heating time decreases also the residual concrete strength.

Some concrete structures are exposed to tropical climate, gas stations and electrical substations. There are tendencies that the heat emanating from these installations may have an adverse effect on the concrete component present. As concrete usage increases globally, the risk of exposing it to temperature also increases [7]. It is essential that the compressive strength properties of concrete subjected to temperatures are clearly understood [9].

The properties of concrete deteriorate when it is subjected to high temperature as in a fire due to the changes in the chemical composition and physical properties of cement paste and aggregate [10]. However, the mechanical properties of concrete exposed to elevated temperatures have been widely studied but temperatures between 25ºC and 100ºC for one-hour duration for grade 30 concrete has been scarcely studied. This study is relevant due to the fact that concrete structures are normally exposed to these temperatures in the tropical region. Creating database for the effect of mild temperature on grade 30 concrete using response surface methodologies will create awareness of its behavioural pattern to practitioners in the construction industry.

MATERIALS AND METHODS

Lafarge Portland cement of grade 42.5, 20 mm coarse aggregate, fine aggregate obtained from a dealer along Oluku, Benin City and water were the material used in this study. The tools used consisted of steel moulds (100 mm x 100 mm x 100 mm size), shovel, head pans and muffle electric furnace provided for in Civil Engineering Laboratory, University of Benin, Nigeria. Grade 30 concrete design mix was carried out and the various weight of the cement content, fine aggregate, coarse aggregate and water/cement ratios were obtained and imputed in the response surface environment which conforms to the minimum standard of BS 1881: Part 108 [11] for concrete making.

However, the grade 30 concrete that was prepared were cured for 28 days and were exposed to temperatures of 25ºC, 62.5ºC and 100ºC for one-hour duration due to the fact that concrete structures can resist fire for one duration according to the requirements of BS 8110 Part 1 [12]. The specimen was cooled for 24 hours at 25ºC temperature and crushed to obtain their respective residual compressive strength according to BS EN 12390:3 [13] methodology. Data were sourced from various laboratory test conducted which includes sieve analysis test, specific gravity test, and compressive strength test respectively.

Sieve analysis test

The fine aggregate was subjected to sieve analysis test according to [14]. The result is shown in Figure 1 below

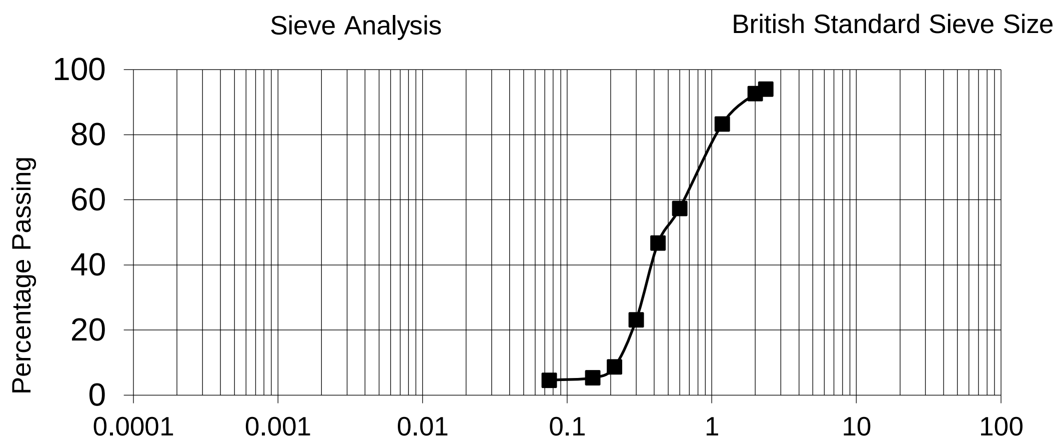

Figure 1: Sieve analysis for the fine aggregate

Specific gravity test

The samples of the fine aggregate were subjected to specific gravity test according to ASTM C127 [15] methodology. The specific gravity of 2.7 was obtained for the fine aggregate. This falls within the minimum requirement for fine aggregate of 2.4 to 2.7.

Regression equations depicting the residual compressive strength of the grade 30 concrete with the temperatures, w/c ratios, cement content, fine and coarse aggregate content were adopted using a statistical package, Design-Expert Software 7.0.0. This software was adopted because it helps in designing the experiments before laboratory works were carried out. The application of Response Surface Methodology (RSM) using the Central Composite Design (CCD) was done.

RESULTS AND DISCUSSION

The response (residual compressive strength) on the independent variables (temperatures, w/c ratios, cement content, fine and coarse aggregate content of the concrete) was studied. The temperature values ranged between (25 to 100) ºC in the DOE. The results obtained are shown in Table 1.0 which gave some response value for the residual compressive strength of the concrete and Table 2.0 which gave the ANOVA values for the experiment.

The p-value of 0.0338 as shown in Table 2. reveals that the linear model is significant. However, cement content, w/c ratio, fine and coarse aggregate content was not significant in the linear model. It indicates that these aforementioned independent variables are not affecting the residual compressive strength but only temperature. The adjusted R^2 of 0.1630 in Table 2 shows that 16.30% of the systematic variations in the residual compressive strength of the concrete are accounted for by the independent variable of temperature. There was increase of compressive strength as the temperature increases. The optimum compressive strength of the concrete at 62.5°C and 100°C were 40 N/mm^2 and 41 N/mm^2 which translated to 11.8 % and 12.1 % increase of concrete compressive strength when compared to the control's compressive strength of 34 N/mm^2 at 28 days curing duration. The control compressive strengths are concrete samples tested at 25ºC. The increase may be due to the accelerated reaction between the silicates in the fine aggregate with the $Ca(OH)_2$ in the cement paste at that temperature which was corroborated by Vodak *et al.* [16].

Table 1: Design of experiment values and responses

Run	TEMPERATURE (ºC)	CEMENT (kg)	COARSE AGGREGATE (kg)	FINE AGGEGATE (kg)	W/C RATIO	COMPRESSIVE STRENGTH (N/mm^2)
1	62.5	0.99	3.28	1.24	0.54	35
2	62.5	0.99	3.385	1.24	0.485	32
3	100	0.88	3.385	1.24	0.485	33
4	62.5	0.99	3.28	1.27	0.485	30
5	100	1.1	3.385	1.24	0.485	33
6	62.5	0.88	3.385	1.27	0.485	22.5
7	62.5	1.1	3.385	1.21	0.485	33
8	62.5	0.99	3.385	1.27	0.54	31
9	62.5	0.88	3.385	1.24	0.54	35.3
10	100	0.99	3.385	1.24	0.54	32
11	100	0.99	3.385	1.24	0.43	37
12	100	0.99	3.385	1.21	0.485	34
13	100	0.99	3.385	1.27	0.485	30.5
14	62.5	0.99	3.49	1.24	0.43	36
15	62.5	0.99	3.49	1.27	0.485	26.5
16	62.5	0.99	3.385	1.24	0.485	31
17	62.5	1.1	3.28	1.24	0.485	26
18	62.5	0.99	3.385	1.27	0.43	34
19	25	0.99	3.385	1.21	0.485	29.8
20	25	0.99	3.28	1.24	0.485	23
21	62.5	0.99	3.49	1.24	0.54	28.5
22	62.5	1.1	3.385	1.27	0.485	30.5
23	62.5	0.88	3.385	1.24	0.43	23
24	62.5	1.1	3.49	1.24	0.485	20
25	25	1.1	3.385	1.24	0.485	28.5
26	25	0.99	3.385	1.24	0.43	32
27	25	0.88	3.385	1.24	0.485	34
28	25	0.99	3.385	1.24	0.54	27.8
29	62.5	0.88	3.49	1.24	0.485	40
30	62.5	0.99	3.49	1.21	0.485	39
31	100	0.99	3.49	1.24	0.485	41
32	25	0.99	3.385	1.27	0.485	20
33	25	0.99	3.49	1.24	0.485	28

34	62.5	1.1	3.385	1.24	0.54	31
35	62.5	0.88	3.385	1.21	0.485	30
36	62.5	0.99	3.28	1.21	0.485	29.5
37	62.5	0.99	3.28	1.24	0.43	34
38	62.5	0.99	3.385	1.24	0.485	32
39	100	0.99	3.28	1.24	0.485	28
40	62.5	0.99	3.385	1.21	0.54	29.5
41	62.5	0.99	3.385	1.24	0.485	32
42	62.5	1.1	3.385	1.24	0.43	27
43	62.5	0.88	3.28	1.24	0.485	38
44	62.5	0.99	3.385	1.24	0.485	32
45	62.5	0.99	3.385	1.21	0.43	33

Table 2: ANOVA for the linear model for concrete exposed to mild temperatures

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	258.14	5	51.63	2.71	0.0338	significant
A-TEMPERATURE	128.82	1	128.82	6.77	0.0130	
B-CEMENT	44.89	1	44.89	2.36	0.1326	
C-COARSE AGGREGATE	15.02	1	15.02	0.7893	0.3798	
D-FINE AGGEGATE	67.24	1	67.24	3.53	0.0676	
E-W/C RATIO	2.18	1	2.18	0.1144	0.7370	
Residual	741.93	39	19.02			
Lack of Fit	741.13	35	21.18	105.88	0.0002	significant
Pure Error	0.8000	4	0.2000			
Cor Total	1000.07	44				
R^2						0.2581
Adjusted R^2						0.1638

CONCLUSION

The optimum results show an 11.8% and 12.1% increase of concrete compressive strength at 62.5°C and 100°C when compared to the control's compressive strength at 28 days curing duration. This depicts that grade 30 concrete improved in compressive strength when temperature increased from 25°C and 100°C. The adjusted coefficient of determination (R^2) was 0.1630 which means that the independent variable was able to explain 16.30 % of the residual compressive strength variation in the linear model. This work has provided a database for grade 30 concrete exposed to 25°C and 100°C temperatures for one-hour duration.

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