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Effect of High Temperature on the Residual Strength Properties of Concrete

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Abstract

The purpose of this work is to determine the effect of high temperature on the residual strength properties of concrete. The cement used for this work was Ordinary Portland cement of grade 42.5 meeting the requirement of type 1 cement. The fine aggregate and coarse aggregate used to produce concrete were all obtained from Benin City, Edo state, Nigeria. Sieve analysis was carried out for the fine aggregate. Water/cement ratio of 0.55 were used to produce a total of 84 samples of 100mm x 100mm concrete cubes for grade 30 (C30) concrete design mix. The samples were exposed to high temperatures of 300^0C to 800^0C for one (1) hour in a muffle electric furnace. The results obtained at 28days for23^0C, 300^0C, 400^0C, 500^0 C, 700^0C and 800^0C are 38.2N/mm^2, 35.0N/mm^2, 32.9N/mm^2, 30.9N/mm^2, 24.7N/mm^2, 17.2N/mm^2 and 10.6N/mm^2 respectively. The percentage reduction of the compressive strength from 23^0C to 800^0C is 27.7%. These depict that concrete compressive strength reduces to 27.7% when exposed to high temperature of 800^0C for one hour.

1.0 Introduction

Concrete is one of the most widely used construction materials prone to high temperature when exposed to fire. The mechanical properties such as strength, modulus of elasticity and volume stability of concrete are considerably reduced during these exposures. However, the residual strength of concrete after fire incidence are still of importance in determining the load carrying capacity of the fire-damaged structure [1].

With the increase of incidents caused by major fires in buildings and other structures coupled with the effects of global warming, concrete is now subjected to higher temperatures other than the ambient conditions. Moreover, long periods of exposure of concrete to high temperatures introduce physical-chemical changes in its properties that lead to mechanical strength decay which produces losses in the safety of the structure.

There is a fundamental problem caused by high temperatures that is, the separation of concrete masses from the body of the concrete element “spalling phenomenon ". Spalling of concrete leads to a decrease in the cross section area of the concrete and thereby decreases the resistance to loads, as well as the reinforcement steel bars become exposed directly to high temperatures [2].

When fire engulfs concrete structure, it affects the chemical and physical composition. Micro-cracks are induced through the material as temperature exceeds 300^0C. Calcium hydroxide $(Ca\ (OH)\ _2$dissociates at 530^0C resulting in shrinkages of concrete. Calcium-Silicate-Hydrate (CSH) gel, which is the strength giving compound of the cement paste, decomposes further above 600^0C. The concrete crumbles finally above 800^0C[3].The retained properties of concrete after such exposures are of great importance in terms of serviceability of the structure. The restoration of the fire damaged structure to an acceptable level is more economical, both in terms of cost and time, than demolishing and re-constructing it all over again.

Ultrasonic Pulse Velocity (UPV) techniques are normally used in concrete to detect and analyse the state of deterioration in advance. It is the best and most reliable non destructive method since the relationship between pulse velocity and elastic properties of concrete have been well established[4].

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Table1: Pulse Velocity Rating for Concrete Quality

Pulse Velocity (Km/sec)	Concrete Quality (Grading)
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful

(Source: [7])

The relationship between the residual strength and ultrasonic pulse velocity using neural network analysis was studied in [5]. The Authors were able to predict the residual strength of concrete at elevated temperatures, in which the residual strength was defined as the ratio of the compressive strength of the heated specimen to that of the unheated specimen. Poon et at. [6] discussed a certain degree of strength recovery of the heated concrete depending on the type of storage after fire.

This work is aimed at determining the residual compressive strength of concrete when exposed to high temperatures using ultrasonic pulse velocity (UPV).

2.0 Materials

The cement used for this work was Ordinary Portland cement of grade 42.5 meeting the requirement of ASTM C150 type 1 cement. The fine aggregate and coarse aggregate used to produce concrete were all obtained from Benin City, Edo state, Nigeria. Sieve analysis was carried out for the fine aggregate while consistency test were carried out on the cement paste of cement. Water/cement ratio of 0.55 were used to produce a total of 84 samples of 100mm x 100mm concrete cubes for grade 30 (C30) concrete design mix. The samples were exposed to high temperatures of 300^0C to 800^0C for one (1) hour in a muffle electric furnace.

3.0 Compressive Strength Test

With the addition of water into the mix, the whole mix was then mixed thoroughly into a fine paste. Meanwhile, the concrete moulds were oiled (lubricated) to prevent the concrete from sticking to them and for easy de-moulding. The concrete was then poured into the concrete mould and placed on the compacting machine, which when switched on vibrated the concrete moulds, making the concrete to lose the trapped air in the mix. This was allowed for 2 minutes before the switching off. The excess concrete was cleared from the surface with the aid of the trowel and the concrete moulds were marked for easy identification to prevent mix-up.

After the cast of the samples, they were allowed to set and harden for 24 hours before de-moulding.

After de-moulding the samples were placed in a curing tank for specified numbers of days (i.e., 7 and 28 days respectively). At each specified period of days, the samples were taken to the electric furnace for heating at various temperatures ranging from 300^0C to 800^0C and were allowed to cool down to room temperature i.e. 23^o C. Ultrasonic pulse velocity (UPV) machine were used on each sample before crushing in a compression machine to determine the residual compressive strength of the concrete.

4.0 Ultrasonic Pulse Velocity (UPV) Test

In the present study, Ultrasonic Pulse Velocity (UPV) tests were performed according to procedures prescribed in ASTM C 597. A testing apparatus consisting of a pulse generator, a pair of transducer, an amplifier, a time measuring circuit, and connecting cables is used. Ultrasonic measurements are performed by direct UPV method. UPV machine is switched on and the pair of transducer (the receiver and transmitter) is placed in the opposite direction on the concrete. The surface of the transducer is lubricated first before placing on the concrete and the readings on the display screen is recorded. This reading is time of travel of pulse velocity or simply pulse time. The ratio of the path length to the pulse time gives the pulse velocity.

Table 2: Particle Size Distribution for Fine Aggregates

APPROX IMPERIAL EQUIV (inches)	BRITISH STANDARD SIEVE SIZES (mm)	RETAINED IN gm	PASSING IN gm	PASSING IN (%)
3/16	5			
⅛	3.35		100.00	100.00
7	2.36	1.76	98.24	98.24
10	2	1.8	96.44	96.44
14	1.18	9.45	86.99	86.99
25	0.6	30.65	56.34	56.34
36	0.425	23.9	32.44	32.44
52	0.3	13.33	19.11	19.11
72	0.212	10.57	8.54	8.54
100	0.15	4.85	3.69	3.69
200	0.075	3	0.69	0.69

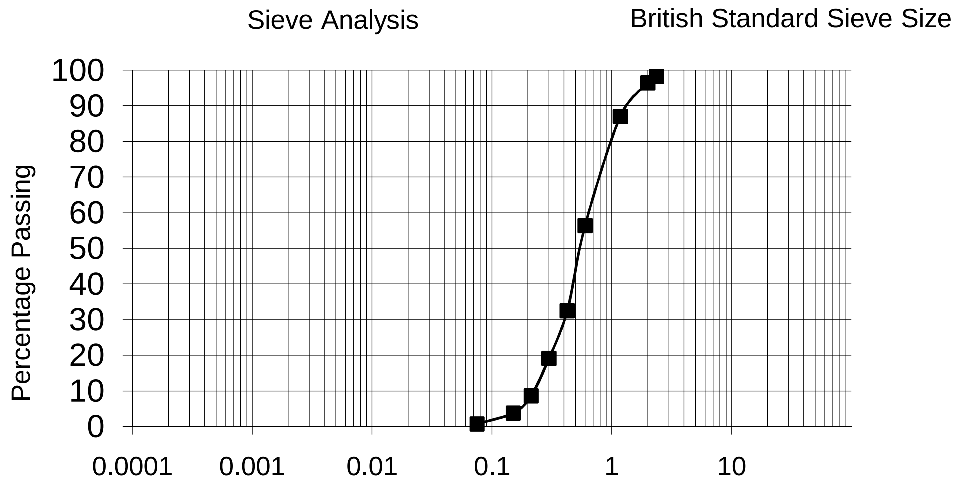

Figure 1: Particle Size Distribution for Fine Aggregates

Table 3: Average Pulse Velocity and Concrete Quality Grading for Concrete at 7 days Curing

Temperature (^oC)	Pulse Velocity (Km/s)	Concrete Quality (grading)
23	3.95	Good
300	3.61	Good
400	3.18	Medium
500	2.62	Doubtful
600	1.73	Doubtful
700	1.09	Doubtful
800	0.51	Doubtful

Table 4: Average Pulse Velocity and Concrete Quality Grading for Concrete at 28 days Curing

Temperature (^oC)	Pulse Velocity (Km/s)	Concrete Quality (grading)
23	4.30	Good
300	3.03	Medium
400	2.48	Doubtful
500	2.45	Doubtful
600	1.81	Doubtful
700	1.16	Doubtful
800	0.76	Doubtful

Table 5: Average Pulse Velocity and Compressive Strength Results of 28 days Cured Concrete

Temperature (^oC)	Time (μS)	Path Length (mm)	Pulse Velocity (Km/s)	Failure Load (KN)	Residual Compressive Strength (N/mm$^{2)}$
23	23.28	100	4.30	382	38.2
300	33.55	100	3.03	350	35.0
400	35.78	100	2.48	329	32.9
500	41.15	100	2.45	309	30.9
600	48.08	100	1.81	247	24.7
700	89.90	100	1.16	172	17.2
800	136.47	100	0.76	106	10.6

Table 6: Average Pulse Velocity and Compressive Strength Results of 7 days Cured Concrete

Temperature (^oC)	**Time (μS)**	**Path Length (mm)**	**Pulse Velocity (Km/s)**	**Failure Load (KN)**	**Compressive Strength (N/mm$^{2)}$**
23	25.33	100	3.95	317	31.7
300	27.73	100	3.61	296	29.6
400	31.50	100	3.18	277	27.7
500	38.26	100	2.62	252	25.2
600	58.03	100	1.73	234	23.4
700	96.15	100	1.09	194	19.4
800	196.15	100	0.51	141	14.1

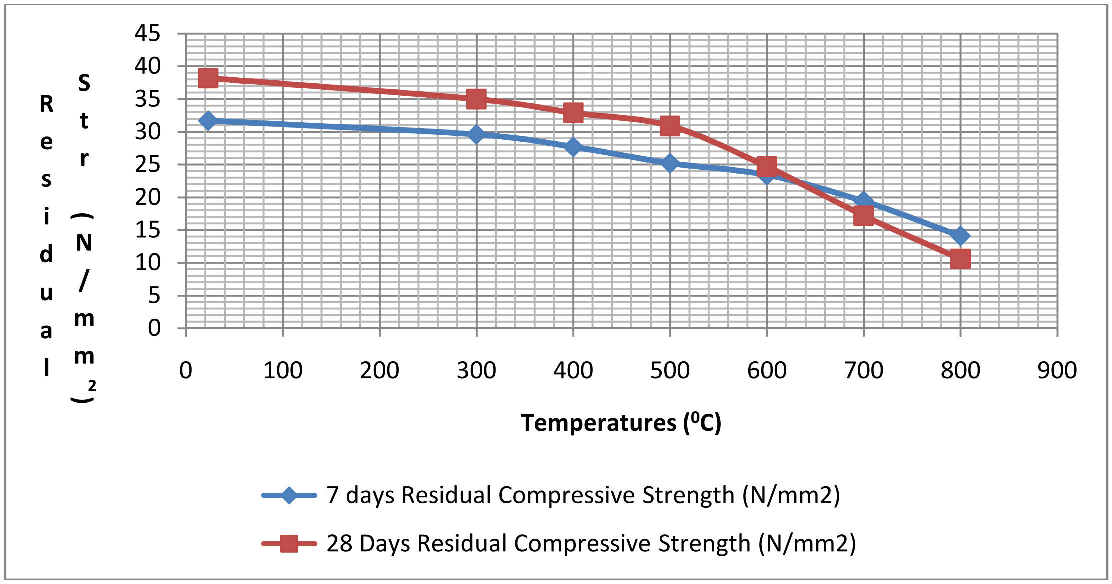

Figure 2: Relationship between Temperatures and Residual Compressive Strength of Concrete

5.0 Results and Discussions

Table 2 and Figure 1 reveals the results for the sieve analysis of the fine aggregate which falls into zone 3 according [9] making it fit for concrete use. Figure 2 shows the relationship between temperature and residual compressive strength. As the temperature increases the compressive strength reduces and finally to 10.6N/mm^2 where it finally crumbles as discussed by [3]. Table 5 and Table 6 shows the residual compressive strength test results for 7 and 28 days curing period at 23^{0}C to 800^{0}C. The concrete was able to resist up to 500^{0}C of temperature for one hour before deterioration with a residual compressive strength of 30.9N/mm2at 28days. These met the characteristic strength of grade C30 concrete requirements at 28days period of curing. Similarly, Table 3 and Table 4showthe pulse velocity measurements for 7 and 28 days respectively. The UPV was able to show that the concrete was serviceable up to 300^{0}C at 28 days.

6.0 Conclusion

Due to the compressive strength results and the pulse velocity results obtained from Fig 2, Table 4 and Table 5 at 28 days period of curing. The following can be inferred:

1. Grade C30 concrete can resist high temperatures up to 500^{0}C without deterioration for one hour.
2. The residual compressive strength of grade 30 concrete is about 27.7% of its initial compressive strength when it is exposed to high temperature of 800^{0}C for one hour. This buttresses the fact discussed by [3] that the Calcium-Silicate-Hydrate (CSH) gel, which is the strength giving compound of the cement paste, decomposes further above 600^{0}C and finally crumbles at 800^{0}C.
3. Ultrasonic pulse velocity can be used to detect the serviceability of concrete after a fire incident.

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