International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 17, Issue 10 (October. 2021), PP. 08-14

Effect of Elevated Temperature on Compressive Strength of Fly Ash Blended Cement Concrete

Arimanwa, J.I.[1], Arimanwa, M.C.[2], Maduagwu, J.C.[3], Awodiji, C.T.G.[4]
[1]*Civil Engineering Dept, Federal University of Technology, Owerri, Imo State, Nigeria*
[2]*Cvil Engineering Dept, Federal Polytechnic Nekede Owerri,, Imo state, Nigeria*
[3]*Civil Engineering Dept, Federal University of Technology, Owerri, Imo State, Nigeria*
[4]*Civil Engineering Dept, University of Portharcourt, Rivers State, Nigeria*
Corresponding Author: Arimanwa, J. I.

ABSTRACT
This study evaluates the effect of elevated temperatures on the compressive strength of fly ash blended cement concrete. The materials used for this research were ordinary Portland cement, clean river sand as fine aggregates, crushed granite chippings as coarse aggregates, potable water, fly ash and Rheobuild (a water reducing admixture). The characteristic strength of 25 N/mm^2 corresponding to the mix design and a target mean crushing value of 38.12 N/mm^2 were used. Fly ash was added in percentages of 0%, 5%, 10%, 15%, 20%, and 25% of ordinary Portland cement. 1.2% of Master Rheobuild ® 561M was combined to all fly ash blended mixes. Batching was done by weight. Fly ash cement concrete were produced for a mix ratio of 1: 1.43: 2.44 with a water cement ratio of 0.42. A total of 216 concrete cubes were prepared and cured for 28days, 60days and 90days by immersion in water. After curing, 3 cubes for each mix ratio were tested in compression at of 25^{0}C temperature. This procedure was then repeated for samples that were heated up to 200°C, 400°C, 800°C and 1200°C and then cooled gradually to room temperature. The samples were exposed to heat in a furnace at an increasing rate of 10°C/min until the required temperatures were reached. They were maintained at each target temperature for 60 minutes. The highest compressive strength value of 45.90Nmm^{-2} was obtained for e 10% fly ash content from 90 days samples exposed to 200°C. The values of compressive strength of the samples showed continuous decrease when heated beyond 200°C.
***Keywords**: Fly ash, elevated temperature; rheobuild; concrete; compressive strength.*

Date of Submission: 18-10-2021 Date of Acceptance: 02-11-2021

I. INTRODUCTION

Fire resistance of concrete is its ability to withstand fire or to give protection against high temperatures due to fire outbreak. This involves the ability of concrete structural elements to continue to perform their specific structural functions or confine fire or both [1]. Fire resistance is the property of materials or their assemblies that prevents or retards the passage of excessive heat, hot gasses or flames under condition of use [2]. It is a major serviceability consideration in the design of structures. According to [3], a structure is designed to possess an appropriate degree of defiance to flame penetration, heat transmission and collapse.

The behavior of structural elements during a fire is determined by their strength at elevated temperatures. The temperature attained during a fire outbreak depends on the source of the fire and how long it lasts. Concrete is commonly used in all load bearing elements of a building such as slabs, beams, columns and footings. The failure of any of these elements during a fire can lead to the failure of part or all of the building.

Fly ash is one of the constituent materials used in the production of fly ash blended cement concrete. There is an increasing rise on the need to curb environmental pollution. Fly ash which would cause environmental pollution when dumped as waste can be reused for strengthening the concrete and that gives a double fold advantage.

This work investigates the effect of high temperatures on concrete blended with different percentages of fly ash and subjected to various higher temperatures of 200°C, 400°C, 800°C and 1200°C. The intention is to expose fly ash blended cement concrete of known strength to high temperatures and monitor the effect of exposure on the compressive strength of concrete.

II. LITERATURE REVIEW

It has been established that fly ash can be used as a pozzolan, supplementary cementitious material and admixture in concrete {[4]; [5] & [6]]. According to [6], the use of fly ash saves cement requirement in concrete, improves durability and imparts several environmental benefits. [7], studied the utilization of fly ash as a partial replacement for cement as well as an additive in concrete. They replaced the cement in the concrete matrix from 5% to 25% and observed that replacing cement with any quantity of fly ash lowered the 28^{th} day compressive strength of the resulting concrete. However, the concrete experienced an improvement in durability and delay in hardening. They concluded that the use of fly ash as partial replacement of cement has economic, environmental and technical benefits such as reducing waste materials, producing a cleaner environment, reducing energy requirement for cement production, reducing carbon dioxide emission due to cement production, improving durability and producing a cheaper concrete.

The performance of concrete like other building materials is adversely affected by heat. [8] agreed with the concept of high temperatures adversely affecting concrete performance. He monitored the effect of heat on high strength concrete. In his study, he subjected concrete with initial compressive strength of 52 N/mm^2 to temperatures up to 300°C and observed that only about 20% of its strength was lost. However, when subjected to temperatures above 300°C the loss in strength was very significant. [9], in their own work, studied the effect of fly ash on strength characteristics of roller compacted concrete pavement. They replaced cement with 20%, 40% and 60% fly ash and tested for compressive, split tensile and flexural strengths after 3, 7, and 28 days. Results showed that increasing the percentage of fly ash reduced all the strength characteristics investigated.

[10] reported, from their studies, a noticeable development in the strength attributes of concrete made with some percentage replacement of ordinary Portland cement (OPC) with fly ash, when put through raised temperature with intermittent cooling. The impact, flexural, tensile and compressive strengths all became greater as the content of fly ash increased up to 25%. [11], in their study on the effects of mixing and curing temperature on the strength development and pore structure of fly ash blended mass concrete, observed that elevated temperature did not affect the early age strength gain of OPC concrete cured in summer but, resulted to an increase in the early gain of strength of concrete made from fly ash and belite. They reported that all concrete investigated experienced long term loss in strength.

[12] investigated to see how volume fly ash concrete will act at very high temperatures from 27^0C to 800^0C at intervals of 200^0C for a 3 hours duration. They noted that the residual compressive strength of the modified concrete was similar to the control concrete. The concrete made with cement alone experienced more loss in weight than those that had fly ash in them. All concrete mix had their weights reduced at increased temperature. Strengths grew as temperature increased up to 400^0C. Only concrete made of 50% OPC and 50% fly ash had an optimum increase in strength at 600^0C after 28 days. Samples of mortar made using fly ash and volcanic ash manifested a remarkable outcome in the early age of the concrete [13]. On the contrary, adjusted samples of fly ash, volcanic ash and slag from an electric arc furnace, gave better strength and lesser weight loss at later ages of curing than the control mix. In the present study, the addition of fly ash in concrete and its strength effects at higher temperature are investigated.

III. MATERIALS AND METHODS

3.1 MATERIALS

Portland-limestone cement designated as CEM II/B-L 32.5R was used for the experiment. Its chemical composition conforms to the provisions of [14]. The initial and final setting times of the cement were 60 mins and 240 mins respectively. River sand of maximum aggregate diameter of 5mm was obtained from Otamiri River in Owerri West Local Government Area of Imo State in Nigeria. It had a water absorption and specific gravity of 8.16% and 2.608 respectively. Crushed granite chippings of sizes ranging from a little above 5mm to 20mm were acquired from Okigwe in Imo State. It had a water absorption and specific gravity of 0.1% and 2.667 respectively. Both aggregates were subjected to the grain size distribution analysis according to [15] and results obtained are presented in Fig 2. Siliceous fly ash obtained from a furnace fired with pulverised coal at Enugu in Enugu State, Nigeria and its chemical composition is as illustrated in Table 1. Results of its particle size distribution are shown in Fig 1. Potable water used for the study was obtained from the Federal University of Technology, Owerri. MasterRheobuild® 561M, a high range water reducing agent was also used for the experiment.

3.2 METHODS

In this study, a mix ratio of 1: 1.43: 2.44 obtained from mix design with water-cement ratio (w/c) of 0.42 was used to prepare the concrete cube specimens. Batching was done by weight. The characteristic strength of 25 N/mm^2corresponding to the mix design and a target mean crushing value of 38.12 N/mm^2 was used. 1.2% MasterRheobuild® 561M, a high range water reducing superplasticizer was added to all fly ash blended mixes. The workability of all fresh concrete was determined according to [16].

Materials were mixed manually using a shovel. The mixing was done on a hard, clean and impermeable surface. For the control test specimens, dry river sand was first deposited on the impermeable surface before cement was added. Both materials were thoroughly combined before the addition of granite chippings. The process of quartering was used in the mixing process to ensure that the materials were properly mixed. Lastly, water was added and the whole batch was thoroughly combined. The slump of the freshly mixed concrete was determined as a measure of workability. Metal molds measuring 150mm x 150mm x 150mm were each filled with concrete in three equal layers with each layer receiving 25 standard tamping using a 25 mm diameter rod. Immediately after preparing the concrete cube specimens they were stored in a place free from vibration and in conditions which would not permit rapid loss of moisture. The specimens were removed from their molds after 24 hours and cured for 28 days by immersing them in a clean water tank in line with the specifications of [17]. A total of 216 concrete cubes were prepared.

After curing the concrete cubes for the required periods, a set of 3 cubes at ambient temperature were weighed and tested for compressive strength. Other sets of three similar concrete samples were exposed to heat in a furnace at an increasing rate of 10°C/min until target temperatures of 200°C, 400°C, 800°C and 1200°C were attained. During heating, specimens were maintained at the required temperature for about 60 minutes. This was done to give enough time for all parts of the samples to attain the target temperatures. Each of these specimens was weighed before being subjected to compressive strength test. These activities were done after allowing the specimens to cool gradually to 25°C temperature. The same procedure was repeated with varying percentages of fly ash and 1.2% of MasterRheobuild® 561M. The average crushing force for each set of concrete cubes was recorded and compressive strength was determined for each mix ratio using the formula given in Eqn. 1. Results obtained are illustrated in Table 3 to Table 5. Also, the weights of specimens determined before testing, were used to calculate their densities as shown in Table 3.

$$f_c = \frac{P}{A} \tag{1}$$

Where f_c= the compressive strength
P = crushing load
A = cross-sectional area of specimen
The mix proportion for preparing the specimen are shown in Table 1.

IV. RESULTS AND DISCUSSION

Chemical composition of fly ash is presented in Table 1. The result of the grain size distribution analyses for fly ash is presented in Figure 1, while that of fine aggregate and coarse aggregate is presented in Figure 2. The coefficient of uniformity, C_U and coefficient of curvature, C_C for fly ash was obtained as 1.97 and 1.37 respectively. The fine aggregate and coarse aggregate have coefficient of uniformity, C_U of 1.62 and 1.52 respectively. While the coefficient of curvature, C_C for fine aggregate and coarse aggregate was obtained as 1.12 and 0.84 respectively. The fly ash and aggregates were uniformly graded.

Table 1: Chemical properties of Fly ash

No	Parameter (Oxide)	% Composition in Fly Ash
1	Silica dioxide (SiO_2)	40.9
2	Aluminum Oxide (Al_2O_3)	18.6
3	Calcium Oxide (CaO)	1.87
4	Iron III Oxide (Fe_2O_3)	28.9
5	Sodium Oxide (Na_2O)	0.56
6	Magnesium Oxide (MgO)	1.01
7	Potassium Oxide (K_2O)	1.44
8	Titanium Oxide (TiO_2)	0.85
9	Loss of Ignition	0.21

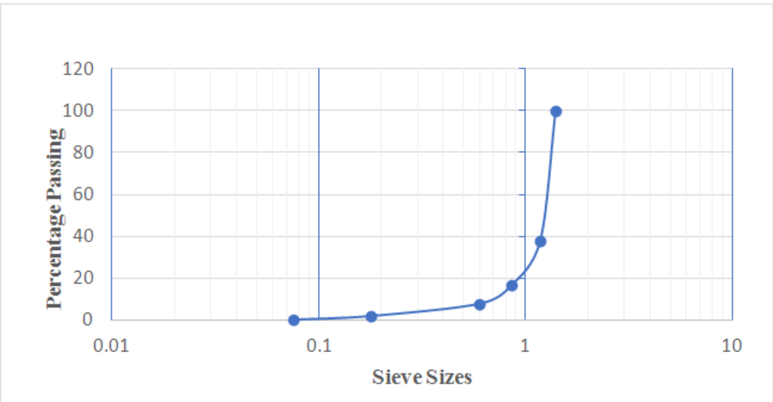

Figure 1: Particle size distribution for Fly ash

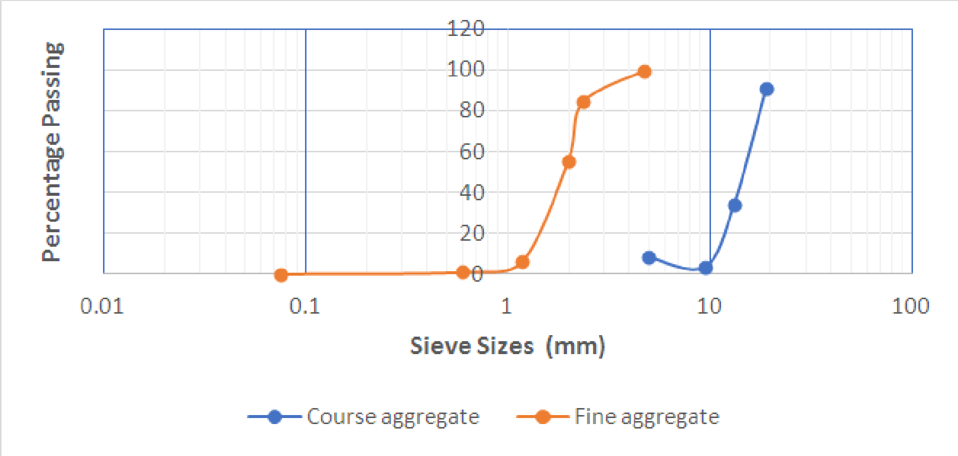

Figure 2: Particle size distribution for Fine aggregate and Coarse aggregate

Values of compressive strength obtained from this study are shown on Tables 2 to Table 4. Also, the relationship between compressive strength and percentage fly ash (for all curing ages) are presented in Figure 3 to Figure 5.

Table 2: 28 days compressive strength test results

Fly ash content (%)	Compressive strength at ambient temperature 25°C (N/mm^2) Control	Compressive strength at 200°C (N/mm^2)	Compressive strength at 400°C (N/mm^2)	Compressive strength at 800°C (N/mm^2)	Compressive strength at 1200°C (N/mm^2)
0	29.50	30.08	28.84	24.80	17.37
5	33.01	33.80	31.37	25.66	20.06
10	36.73	37.54	33.75	28.82	23.56
15	35.08	35.83	32.54	27.64	21.27
20	32.58	33.23	30.32	24.92	18.63
25	31.53	32.03	28.13	22.39	15.92

Table 3: 60 days compressive strength test results

Fly ash content (%)	Compressive strength at ambient temperature 25°C (N/mm^2) Control	Compressive strength at 200°C (N/mm^2)	Compressive strength at 400°C (N/mm^2)	Compressive strength at 800°C (N/mm^2)	Compressive strength at 1200°C (N/mm^2)
0	33.56	34.23	30.22	26.42	20.06
5	37.45	38.30	35.62	27.96	22.44
10	41.63	42.65	38.20	30.44	25.59
15	39.00	40.20	35.73	27.33	21.48
20	35.93	36.45	32.41	24.70	18.93
25	33.93	34.34	29.50	22.65	16.74

Table 4: 90 days compressive strength test results

Fly ash content (%)	Compressive strength at ambient temperature 25°C (N/mm^2) Control	Compressive strength at 200°C (N/mm^2)	Compressive strength at 400°C (N/mm^2)	Compressive strength at 800°C (N/mm^2)	Compressive strength at 1200°C (N/mm^2)
0	41.63	42.34	37.48	30.66	25.59
5	42.30	43.19	39.74	32.87	27.85
10	44.89	45.90	40.33	36.78	31.89
15	41.81	42.66	38.56	33.11	28.44
20	38.12	39.25	34.22	29.00	25.33
25	35.82	36.57	31.48	25.67	20.22

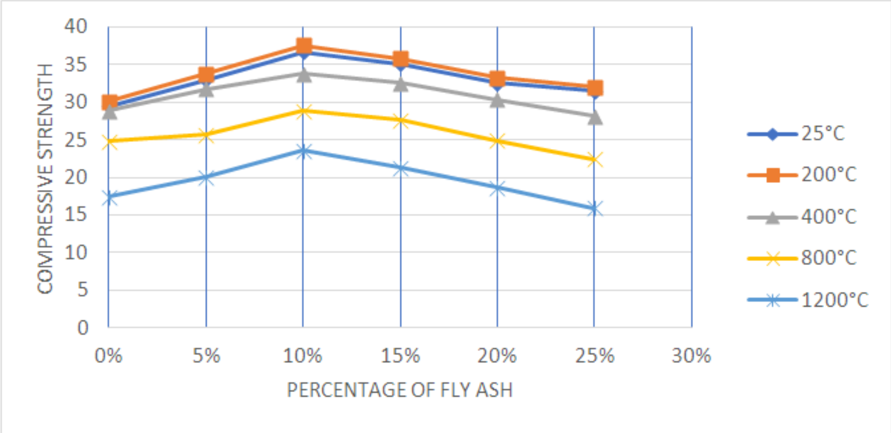

Figure 3: 28 days compressive strength (Nmm-2) against % fly ash

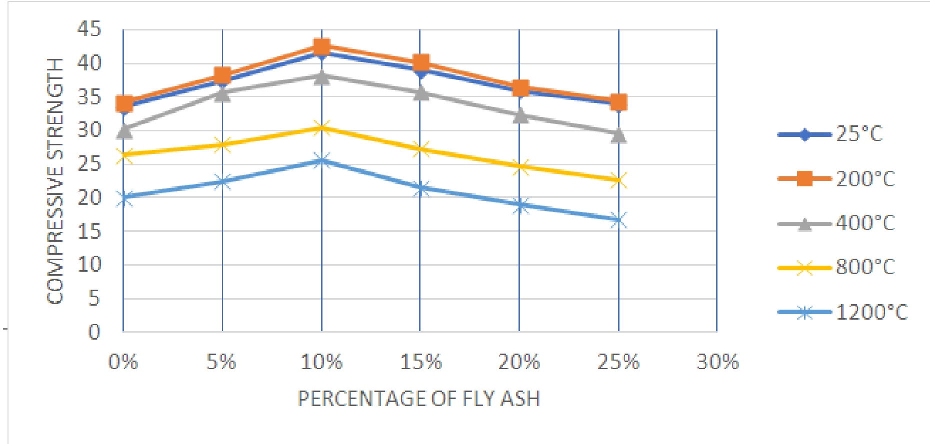

Figure 4: 60 days compressive strength (Nmm-2) against % fly ash

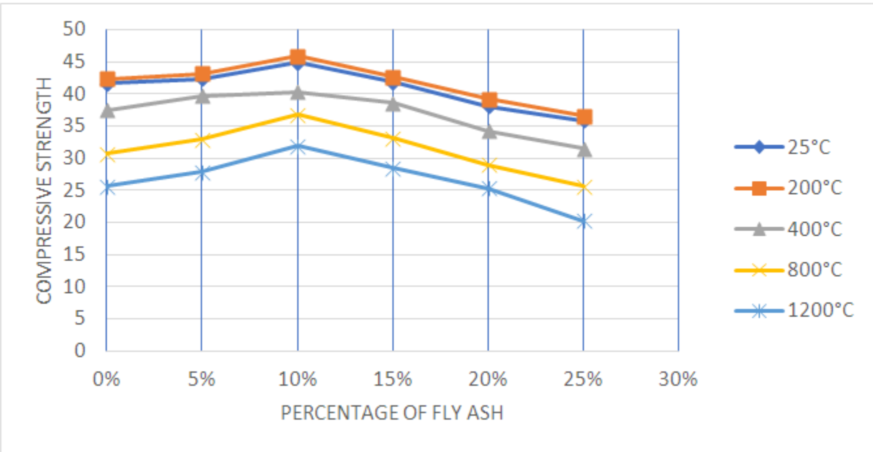

Figure 5: 90 days compressive strength (Nmm-2) against % fly ash

Figure 3, shows the graph of the 28 days compressive strengths against percentage fly ash content. Generally, it can be seen that the compressive strengths, for all specimen, increased gradually from 0% to 10% fly ash content and then decreased gradually up to 25%. The highest compressive strength of 37.54 Nmm^{-2} occurred at 10% fly ash content for specimen at temperature of 200^0C. While, the lowest compressive strength of 15.92 Nmm^{-2} occurred at 25% fly ash content for samples subjected to 1200^0C.

From Figure 4, it is observed that the 60 days compressive strengths for all specimen increased from 0% to 10% fly ash content and then decreased gradually up to 25%. However, maximum compressive strength of 42.65 Nmm^{-2} occurred at 10% fly ash content for specimen put through at the temperature of 200^0C.

Minimum compressive strength of 16.74 Nmm^{-2} occurred at 25% fly ash inclusion for samples subjected to 1200^{0}C.

The 90 days compressive strengths of the concrete specimen as shown in Figure 5 reveals that the value of compressive strengths for all specimen increased from 0% to 10% fly ash content and then decreased gradually up to 25%. The maximum compressive strength of 45.90 Nmm^{-2} occurred at 10% fly ash inclusion for specimen subjected to 200^{0}C elevated temperature. Whereas, the minimum compressive strength of 20.22 Nmm^{-2} occurred at 25% fly ash content for specimen exposed to 1200^{0}C.

Figure 6 to Figure 8 illustrates the relationship between compressive strength and temperature for the 28 days, 60 days and 90 days cured concrete samples respectively.

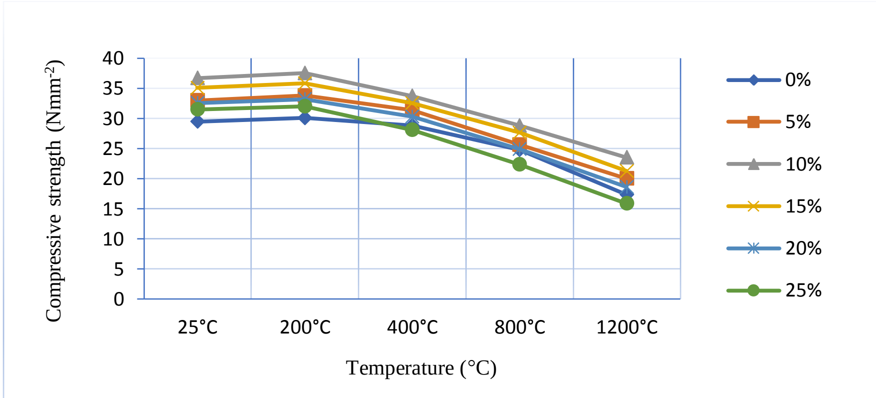

Figure 6: 28 days compressive strength (Nmm^{-2}) against heating temperature (^{0}C)

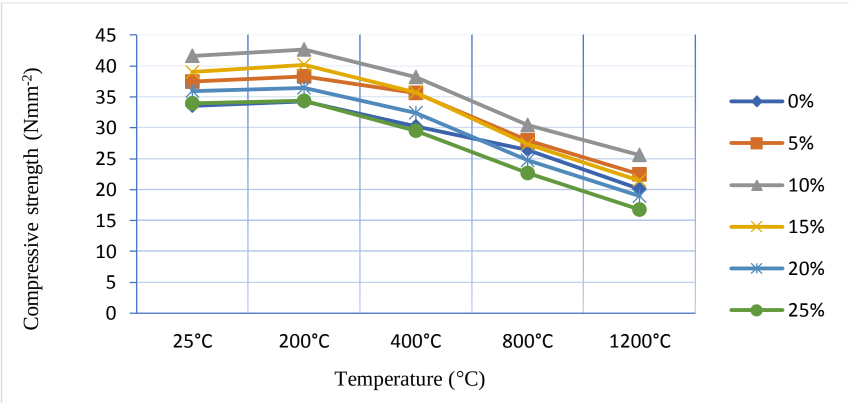

Figure 7: 60 days compressive strength (Nmm-2) against heating temperature (^{0}C).

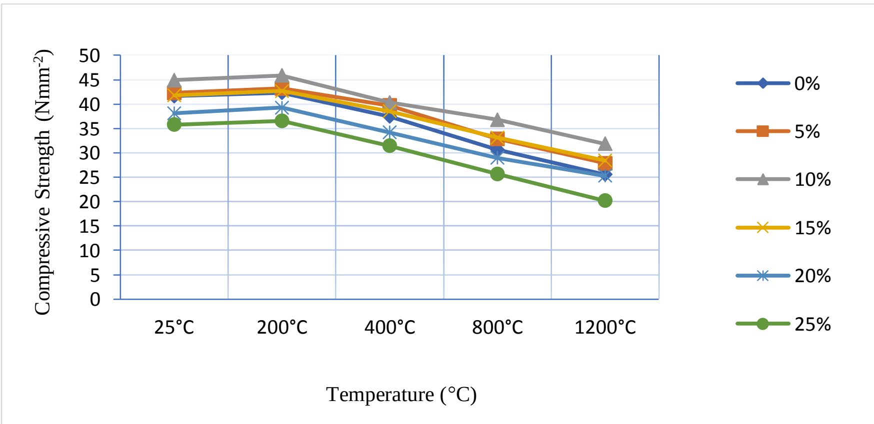

Figure 8: 90 days compressive strengths (Nmm^{-2}) against heating temperature (°C).

From Figure 6, the 28 days compressive strength values increased from 25^{0}C ambient temperature to 200^{0}C before decreasing gradually up to 1200°C. Figure 7 shows the graph of the 60 days compressive strengths against the heating temperatures. The compressive strengths value here increased gradually from 25°C to 200°C and then started decreasing up to 1200°C. For samples cured for 90 days (as shown in Figure 8), compressive strength values increased gradually from 25°C to 200°C before decreasing up to 1200°C.

V. CONCLUSIONS

From this present study, the following conclusions are made;

- The longer the curing age, the higher the compressive strengths for all percentage of fly ash inclusion.
- The specimen tested at 28 days, 60 days and 90 days had their optimum strengths recorded at a temperature of 200^0C.
- Prolonging the heating time of the fly ash cement concrete decreases its compressive strength.
- The highest compressive strength value of 45.90 Nmm^{-2} was obtained at 10% fly ash content from the 90 days samples subjected to 200°C temperature.

REFERENCES

[1]. The Constructor−Civil Engineering Home for Civil Engineers. "What is Fire Resistance of Concrete? Mechanism and Factors". Available from https://theconstructor.org> concrete

[2]. New York City Building Code (NYCBC). "Fire and smoke protection features": Section BC 702 (2014). Available from www1.nyc.gov

[3]. Code of Practice: Structural use of Concrete, 2013.

[4]. Lawson, J. R., Phan T.L. & Davis F. "Mechanical properties of high performance concrete after exposure to elevated temperatures". National Institute of Standards & Technology, 6475 (2000): 1 – 8.

[5]. Indian Standard, (2003). IS 3812 -1: Specification for Pulverized fuel ash - For use as pozzolana in cement, cement mortar and concrete (CED 2: cement and Concrete).

[6]. Wankhede, P. R. & Fulari, V.A. "Effect of fly ash on properties of concrete". International Journal of Emerging Technology and Advanced Engineering (2014): 2250-2459.

[7]. Patil, S.L., Kale, J.N. & Suman, S. "Fly ash concrete: A technical analysis for compressive strength". International Journal of Advanced Engineering Research and Studies, 2 (1), 2012: 128- 129.

[8]. Al Sheikh, S.M. "Mechanical properties for high performance concrete expose to high temperature". International Journal of Civil and Structural Engineering, 2(2) 2011.

[9]. Pavan, S. & Krishna, S. R. "Effect of fly ash on strength characteristics of roller compacted concrete pavement". Journal of Mechanical and Civil Engineering, 11(6) 2014: 04- 08.

[10]. Patil, S. & Prakash, K. B. "Study on the effect of elevated temperature with intermittent cooling on the properties of concrete". International Journal of Science and Research. 4 (2) 2015: 715-718.

[11]. Ki-Bong, P. & Takafumi, N. "Effects of mixing and curing temperature on the strength development and pore structure of fly ash blended mass concrete". Advances in Materials Science and Engineering 27 (2017) doi; https:doi.org/10.1155/2017/3452493

[12]. Ramesh, K. V, Dharma, M. & Rekha, K. "A study of high volume fly ash concrete exposed to elevated temperature". American Journal of Engineering Research. 5 (11) 2016: 227 – 238.

[13]. Khurram, N., Khan, K., Saleem, M. U, Amin, M. N & Akmal, U. "Effect of elevated temperatures on mortar with naturally occurring volcanic ash and its blend with electric arc furnace slag". Advances in Materials Science and Engineering 27 (2018). doi; https:doi.org/10.1155/2018/5324036

[14]. BS EN 197-1: Cement, Composition Specifications and Conformity Criteria for Common Cements, 2011

[15]. BS 812- 103: Methods for determination of particle size distribution. British Standard Institution, 1989.

[16]. BS EN 12350-2: Testing concrete. Slump test. British Standard Institution, 2009.

[17]. BS 1881-111: Method of normal curing of test specimens (20^oC method). British Standard Institution, 1983.

Arimanwa, J. I. "Effect of Elevated Temperature on Compressive Strength of Fly Ash Blended Cement Concrete." *International Journal of Engineering Research and Development*, vol. 17(10), 2021, pp 08-14.