# Properties of Concrete at Elevated Temperatures Using Selected Brands of Ordinary Portland Cement

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## Abstract

*In recent times, there has been a serious controversy as to whether the different brands of OPC commonly used in Nigeria can attain adequate strength and even the Standard Organization of Nigeria (SON) attributed the incidences of building collapse in the country to this assumption. This has prompted researchers to investigate the properties of concrete produced with various brands of the cement produced in the country. This study therefore evaluates the properties of concrete made with different Nigerian brands of OPC exposed to an elevated temperature. Four brands of Ordinary Portland Cement commonly available in Nigeria were used in this project to produce different concrete specimens which were labeled A, B, C and D. a total of seventy two (72) specimens of size 100mm x 100mm x 100mm cubes were produced using a nominal mix of 1:2:4 and W/C ratio of 0.55. After curing the concrete specimens produced in water for 28days, 36 of the specimens were exposed to an elevated temperature of 800°C, 1000°C and 1200°C for 3hrs while the remaining 36 were used as control. Thereafter, compressive strength of the concrete specimens was determined. The average compressive strength obtained for concrete specimen made with cement brand A, B, C and D exposed to 800°C were 6.27N/mm$^2$, 5.08N/mm$^2$, 5N/mm$^2$ and 6.4N/mm$^2$ respectively while at 1000°C the compressive strength values were 3.03N/mm$^2$, 1.97N/mm$^2$, 2.57N/mm$^2$, and 3.27N/mm$^2$ respectively. At 1200°C, all the concrete specimens melted. Result obtained shows that concrete specimen produced with cement brand D has better compressive strengths when compared to A, B and C. It is concluded that cement D showed higher compressive strength after its exposure to elevated temperature. It is therefore recommends that cement D be used in areas where concrete is likely to be exposed to high elevated temperature.*

**Keywords:** Brands of Cement, Elevated Temperature, Properties, Compressive Strength

## INTRODUCTION

Concrete is a fundamental construction material used to fulfill the housing and infrastructural need of the society. According to Venkatesh (2014), is widely known as a primary structural materialused in construction because of its numerous advantages which include strength,durability, ease of fabrication, and non-combustibility properties,it has over other construction materials. Its basic constituent includes conventional fine and coarse aggregate, cement and water. The cement is responsible for the hard matrix the glue the aggregate particle to form the concrete. Example of such is ordinary Portland cement (OPC). According to Neville and Brooks (2010), OPC is obtained by initially adding together calcareous and argillaceous, or other silica, alumina and iron oxide-bearing materials, burning them at a clinkering temperature and grinding the resulting clinker. Houst, Bowen and Siebold (2010), reported that Ordinary Portland Cement composed of roughly five mineralogical phases; Alite ($C_3S$), Belite ($C_2S$), Celite($C_3A$), Felite($C_4AF$) and gypsum.

Fire is known as one of the most severe environmental conditions to which structures may be subjected to.It is essential that concrete structural members when used in buildings should satisfy appropriate fire safety requirements specified in building codes (EN 1991-1-2, 2002; EN, 1992-1-2: 2004; ACI 216.1, 2007; ACI-318, 2008). Fire resistance is the period duringwhich a structural member exhibits resistance with respect to structural integrity, stability, and temperature transmission (Venkatesh, 2014). According to Kodur and Raut (2010), concrete proves to have an excellent fire resistance property when exposed to elevated temperature compared to any building material. This excellent fire resistance is due to its constituent materials which chemically combine to form an inert material which has low thermal conductivity, high heat capacity, and slower strength degradation with temperature. It is due to its slow rate in transferring heat and strength loss that enables concrete to act as an effective fire shield not only between adjacent spaces but also to protect itself from fire damage (Kodur and Raut, 2010).When a structural member is subjected to a defined elevated temperature at a particular time, the exposure will cause a predictable temperature distribution in the member as the temperature continue to increased, it causes deformations and property changes in the constituent materials of structural member (Venkatesh2014).

Matawal (2013) reported that Cement is responsible in a great deal for strength development in concrete. The Alite, Belite, Celite and Felite are responsible for early cement strength, strength development at 28 days, setting time and heat of hydration and cement coloration respectively. The gypsum added during grinding of clinker adjusts setting time and improves cement soundness. When concrete made with OPC is subjected to elevated temperature, numerous transformations and reactions occur. Apart from the crystalline transformations occurring mainly in the aggregate materials during heating, anumber of degradation reactions also occur in the cement paste (Naus, 2006). Cement paste if exposed to elevated temperature results in drying. When hardened concrete is exposed to elevated temperature, free water evaporates first, followed by capillary water, and finally by physically bound water. The process of removing water that is chemically bound with cement hydrates is the last to be initiated (Hager, 2015).

The mechanical properties of cement paste are strongly affected by chemical bonds and cohesion forces between sheets of calcium silicate hydrate (C-S-H) gel. It is assumed that approximately 50% of cement paste strength comes from cohesion forces. Therefore, the evaporation of water between C-S-H gel sheets strongly affects the mechanical properties of the cement paste (Hager, 2013). This research therefore evaluated the properties of concrete made with some selected brands of Nigerian OPC exposed to elevated temperature.

The properties of concrete when exposed to elevated temperature are more complex than most materials used for construction because, the reason is not only that concrete is acomposite material whose constituents have different properties; its properties also depend onmoisture and porosity. Therefore exposing concrete to elevated temperature affects its mechanical and physical properties, It distort and displace the element of the concrete, and under certain conditions, the concrete surfaces mightspall due to the buildup of steam pressure (Naus, 2006). The most commonly used cementitious material in the Nigerian construction industry is the Ordinary Portland Cement (OPC) and recently there has been a serious disagreement as to whether the brands of OPC used in the country can attain adequate strength and even the Standard Organization of Nigeria (SON) attributed the incidence of building collapse in the country to this assumption (Joseph and Raymond 2014). This prompted researchers to investigate into the various properties of concrete produced with various brands of the cement produced in the country.

Joseph and Raymond (2014) evaluated the rate of strength development of concrete made using selected Nigerian cement and discovered that at a range of between 33.5N/mm2 to 34.0N/mm2, the strength of concrete made using most of the selected brands of cement meet the minimum strength requirement of 32.5 N/mm2 for grade 32.5 cement used for the investigation. In a research carried out by Alhaji (2016) to test the effects of sugar as a retarder on the properties of concretes made with different brands of ordinary Portland cement and discovered increase in workability of the fresh concrete for all the brands of OPC and when an optimum dosage was used, properties of the hardened concrete such as compressive strength, split tensile strength, abrasion resistance and water absorption was also enhanced. Umar (2016), assessed the influence of Rheobuild-600 on concretes made with different brands of Portland cements in Nigeria and reported that in terms of economic importance of the use of Rheobuild-600 super plasticizer in concrete, about 25% of cement and 41% of water costs can be comfortably saved.However serious attention was not given to the evaluation of the behavior/ properties of these brands of cement when exposed to elevated temperature.This research therefore evaluates the properties of concrete made with different Nigeria brands of OPC when exposed to elevated temperature.

Gambo (2014) defines durability of cement concrete as its resistance to deteriorating agencies to which it may be exposed during its service life or which may inadvertently reside inside the concrete itself. Therefore this research will provide some basic information on the most suitable brand of OPC that can withstand elevated temperature when used for concrete production According to Nwankwojike, Onwuka and Ndukwe (2014), coalition of civil society groups and professional bodies in Nigerian construction industry accused cement manufacturers and importer of flooding Nigerian markets with different brands of substandard OPC. This research will help provide information which can serve as a standard that can be used by professional in the Nigerian construction industry because it will enable them to know the resistance to fire of concrete made with different brands of OPC so as to ascertain the fire rating for the different cement concrete.

## MATERIALS AND METHODS

### Materials

Materials used in this project include the following: ordinary Portland cements, coarse aggregate, fine aggregate and water. Detail description is as follows:

***Ordinary Portland cements****:* Five brands of OPC, mostly used across the country were used, they were; Ashaka, Dangote, Sokoto and Bua. The brands of cement were used due to its availability and it is assumed to comply with the requirements of BS 12 (1996). They were obtained from local dealers in Zaria, Kaduna.

***Coarse aggregate****:* The coarse aggregate used was crushed granite (20mm maximum size and retained on a 10mm sieve) obtained from a single quarry site in Zaria. It was sieved in accordance with BS 933 part 1 (1997).

***Fine aggregate***: Clean and air-dried river sand sourced from Samaru, Zaria was used. The range of the sizes of fine aggregate was from 600 micron – 5mmon the B.S test sieve. It was sieved in accordance with BS 112 (1971) to remove larger aggregate sizes and impurities.

***Water*****:** Portable water fit for drinking was obtained from Ahmadu Bello University water works and used throughout the project. The quality of water is assumed to conform to the specification of BS 3148 (1980).

**Methods**

The project was carried using the following processes which include;

***Experimental Program***

*T*he project entails an experimental investigation and the details of the methods employed in the project is as follows

***Preliminary Investigations***

The tests carried out include the physical, mechanical and chemical properties of the materials used for the research which include:

**Particle size distribution**: This helps to determine the grading of the aggregate and it is done by distributing the aggregates both fine and coarse into various particle sizes. This was done in accordance with BS 812-103 (1990).

**Aggregate crushing value**: The advantage of this test is that it helps to determine the resistance of the aggregate to crushing. This was done in accordance to BS 812-110, (1990). Materials and Apparatus used include the following: Aggregate sample, 150mm diameter by 135mm high metal cylinder, 15mm diameter by 600mm length standard rammer, steel plate, plunger, oven and compressive testing machine.

**Chemical properties:** Chemical analysis was carried out at the Defence Industries Corporation of Nigeria (DICON), Kakuri Industrial Layout, Kaduna, Kaduna State of Nigeria using XRF test to determine the chemical composition of the different cement brands.

**Production of concrete specimen:**

i. ***Mix Proportion:*** A nominal mix proportion of 1:3:6 with water-cement (w/c) ratio of 0.55 was used for the production of concrete made with the four type of cement brand. The computation of the quantity of material was done by weight.
ii. ***Mixing and casting of ordinary Portland cement concrete specimens:*** Aggregate used for the production of these concrete were used in their saturated surface dried condition. Cement and the aggregates (both fine and coarse aggregate) were mixed together thoroughly, after which water was added and mixed thoroughly.
iii. ***Test on fresh properties of concrete:*** Fresh property test carried out on concrete made with different brands of all the ordinary Portland cement include:

***Workability Test:*** Workability of concrete specimen made with the different brand of Portland cement was determined using slump method test and the test was carried out in accordance with BS 1881-102 (1983).

***Test on harden properties of concrete***

At hardened state, the concrete specimens were tested to check their resistance to elevated temperature after 28days curing period.

**Resistance to Elevated Temperature**

After curing the cubes for the 28days curing period, 3cubes each from each of the concrete produced with different brand of cement were exposed to elevated temperatures of 800$^{o}$C, 1000$^{o}$C and 1200$^{o}$C for 3 hours.The reason for the variation temperature was done so that any change in trend for the concrete specimens produced could be determined.Compressive strength test was then carried out to determine the effect of the heated concrete after it was removed from the oven and allowed to cool. The compressive strength was determined using the relation in equation 1.

$$\text{Compressive Strength} = \frac{\text{maximum load(KN)X1000}}{\text{Cross} - \text{sectional Area (mm}^2)} \qquad 1$$

## RESULTS AND DISCUSSION

The results presented in this chapter are based on the tests carried out to assess the properties of concrete made with different brands of cement exposed to elevated temperature. The result includesphysical and mechanical properties of the aggregate used and the ability of the concrete to resist elevated temperature properties of the concrete made with the different brands of cement.

### Particle Size Distribution

Figure 1 present the results of sieve analysis of the aggregate (i.e. coarse and fine aggregate). Figure 1 shows that the aggregate used for this project fall partly within zone 1 of the standard grading curve. This means the aggregate used in this research are coarser. The implication of this is that concrete produced with this aggregate might encounter segregation for according to Neville (2011), though such grading is comparatively workable and can, therefore, be used for mixes with a low water/cement ratio or for rich mixes, it is however, necessary to make sure that segregation does not take place.

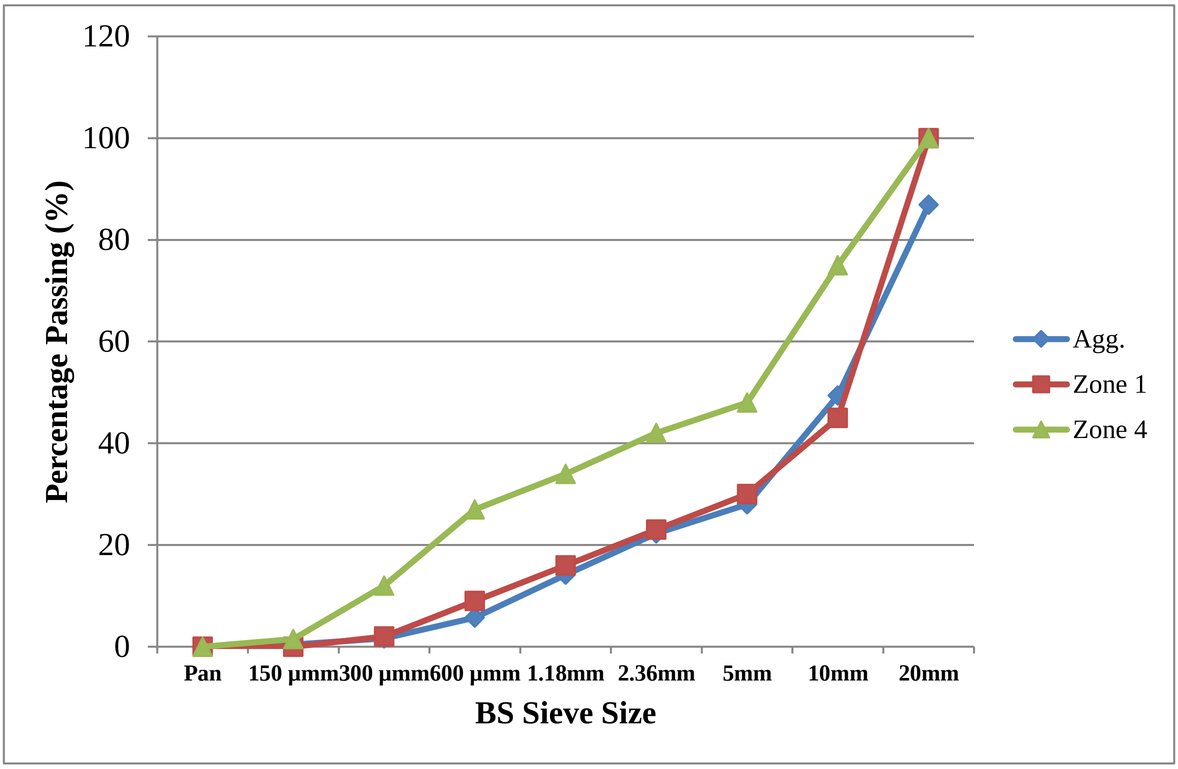


Figure 1: Sieve Analysis for Aggregates

### Bulk density, Specific gravity, aggregate moisture content and aggregate absorption capacity of Fine and Coarse Aggregates

Table 1 shows the bulk density, specific gravity, aggregate moisture content and aggregate absorption capacityof fine and coarse aggregates. The bulk density of the fine and coarse aggregate were found to be 1660 kg/m$^3$ and 1680kg/m$^3$. These therefore satisfy the requirements of BS 812: Part 2 (1995) that states the range for normal weight aggregates to be between 1280kg/m$^3$ and 1920kg/m$^3$.Their specific gravity was found to be 2.5kg/m$^3$ and 2.68kg/m$^3$ respectively. The result obtained shows that it is inline the range of 2.30kg/m$^3$ to 2.90kg/m$^3$ specified by ACI EI 201 (2001).The values obtained for fine and coarse aggregate moisture content were 0.18% and 2% respectively. The absorption capacity for fine aggregate was 3% while that of coarse aggregate was 1%.

Table 1: Bulk density, Specific gravity, and aggregate moisture content and aggregate absorption capacity of Fine and Coarse Aggregates

| Sample | Aggregate Bulk Density(kg/m$^3$) | Specific Gravity (kg/m$^3$) | Aggregate Moisture Content(%) | Aggregate Absorption Capacity(%) |
|---|---|---|---|---|
| Fine Agg. | 1660 | 2.5 | 0.18 | 3 |
| Coarse Agg. | 1680 | 2.68 | 2 | 1 |

**Aggregate Impact Value and Aggregate Crushing Value**

Table 2 present result for the aggregate impact value (AIV) and aggregate crushing value for the coarse used for this project. The percentage of impact the aggregate was found to be 11.43% indicating that the aggregate has good resistance to impact and the values is close to the 45% reported by Gupta and Gupta (2012). The crushing values obtained for the aggregate used was found to be 21.5%. Meaning that the aggregate has higher ability to resist crushing and the value obtain fall within the 45% (Gupta and Gupta 2012).

Table 2: Aggregate Impact Value and Aggregate Crushing Value

| Sample | Aggregate Impact Value(%) | Aggregate Crushing Value(%) |
|---|---|---|
| Coarse Agg. | 11.43 | 21.5 |

Table 3: Chemical Composition of Different Brandsof Portland Cements

| | Brands of Cement | | | | |
|---|---|---|---|---|---|
| | A cement | B cement | C cement | D cement | ASTM |
| Aluminum Oxide ($Al_2O_3$) | 5.6 | 3.5 | 5.0 | 4.1 | 3.0 – 8.0 |
| Silicon Oxide ($SiO_2$) | 14.8 | 11.3 | 15.1 | 15.8 | 17– 25 |
| Iron Oxide ($Fe_2O_3$) | 4.53 | 4.50 | 5.05 | 6.03 | 0.5 – 6.0 |
| Sulphur Oxide ($SO_3$) | 2.25 | 2.53 | 3.48 | 2.38 | 1.3 – 3.0 |
| Potassium Oxide ($K_2O$) | 0.812 | 0.079 | 0.100 | 0.290 | 0.4 – 1.3 |
| Calcium Oxide (CaO) | 69.07 | 75.57 | 67.91 | 68.49 | 60 – 67 |
| Titanium Oxide ($TiO_2$) | 0.33 | 0.18 | 0.30 | 0.23 | – |
| Chromium Oxide ($Cr_2O_3$) | 0.013 | 0.010 | 0.027 | 0.012 | – |
| Manganese Oxide (MnO) | 0.244 | 0.032 | 0.140 | 0.077 | – |

**Chemical Composition of Different Brands of Cement**

Table 3 represents chemical composition of the selected brands of cement used to produce concrete in this project. The aluminium oxide ($Al_2O_3$) and iron oxide ($Fe_2O_3$) percentages of all the four brands of cement used clearly satisfies ASTM C 150 (2005) requirement which states that it should be within the range of 3.0 to 8.0 for the $Al_2O_3$ and 0.5 to 6.0 for the $Fe_2O_3$. The result in the table also shows that D cement had the lowest percentage of aluminium oxide ($Al_2O_3$) content and the percentage of iron oxide ($Fe_2O_3$) content is high which leads to low content of tricalcium aluminate ($C_3A$) while A cement contain the highest percentage of $Al_2O_3$ content and low percentage content of $Fe_2O_3$ which lead to high content of tricalcium aluminate ($C_3A$).

## Properties of Fresh Concrete Specimen

### *Workability*

Table 4 indicates the slump value for concrete made with different brands of Portland cement A, B, C, D respectively. The workability of concrete made with the selected cement brands A, B, C and D fall between very low slump (0 – 25mm).Though the cement C has the lowest slump value followed by cement A, D and B. The decrease in slump could be due to the water cement ratio that was used. Building Research Establishment (BRE) (1997) stated that due to its low slump value, the concrete is suitable for road vibrated by power –operated machines.

Table 4: Slump Value for Different Concrete Specimen

| Specimen | Slump Value(mm) |
|---|---|
| A cement | 17 |
| B cement | 19 |
| C cement | 15 |
| D cement | 18 |

## Properties of Hardened Concrete Specimen

### *Compressive Strength of Concretes Exposed to Elevated Temperature of 800$^o$C*

Figure 4 presents the average compressive strength of control concrete specimen produced with A, B, C and D brands of ordinary Portland cement, cured for 28 days. While Figure 2 presents the average compressive strength of concrete specimen produced with A, B, C and D brands of ordinary Portland cement, cured for 28days and exposed to a temperature of 800$^o$C. From the figure, there was a high decrease in percentage of compressive strength between the control concrete specimen and that exposed to fire. The compressive strength of the control concrete specimen made with A, B, C and D were 20.14 N/mm$^2$, 18.92 N/mm$^2$, 21.08 N/mm$^2$, 28.09 N/mm$^2$ while the value for that exposed to elevated temperature were 6.27N/mm$^2$, 5.08N/mm$^2$, 5N/mm$^2$, 6.4N/mm$^2$ respectively (Figure 2). This represents a percentage decrease of 68.67%, 73.15%, 76.28%, 77.22% respectively.

The decrease in the compressive strength of concrete made with different brands of cement could be attributed to the effect of the temperature it was subjected to. This is because the decrease in compressive strength with temperature may be due to the dehydration of $Ca(OH)_2$ at about 600$^o$C producing CaO and $H_2O$ and even over 700$^o$C compressive strength loss are mostly caused by calcium carbonate dissociation and subsequent $CO_2$ escaped from $CaCO_3$ (Aka, Usman, Umar and Samuel, 2013). Though the concrete produced with D cement has the highest compressive strength after its exposure to elevated temperature at 800$^o$C, this isolated case could be as a result of the variation in the chemical composition.

**Compressive strength of specimens Exposed to elevated temperature of 1000°C**

Figure 4 presents the average compressive strength of concrete made with different brands of cement A, B, C and D exposed to an elevated temperature of 1000°C after being cured for 28days. The compressive strength obtained was 3.03N/mm$^2$, 1.97 N/mm$^2$, 2.57N/mm$^2$, 3.27 N/mm$^2$ (Figure 2). This represents a percentage decrease of 84.96%, 89.59%, 87.81%, 88.36% respectively when compared with the corresponding control values. At 1000°C, the rate of deterioration in compressive strength continues to increase in concrete made with brands A, B, C and D cement. The reason for this deterioration in compressive strength could be due to the high temperature the cement concrete were exposed to according to Naus (2006), changes in the chemical composition and microstructure of the hardened Portland cement paste occur gradually and continuously over a temperature range from room temperature to 1000° C. The concrete made with D brand of cement still possessed the highest compressive strength after its exposure to elevated temperature of 1000°C.

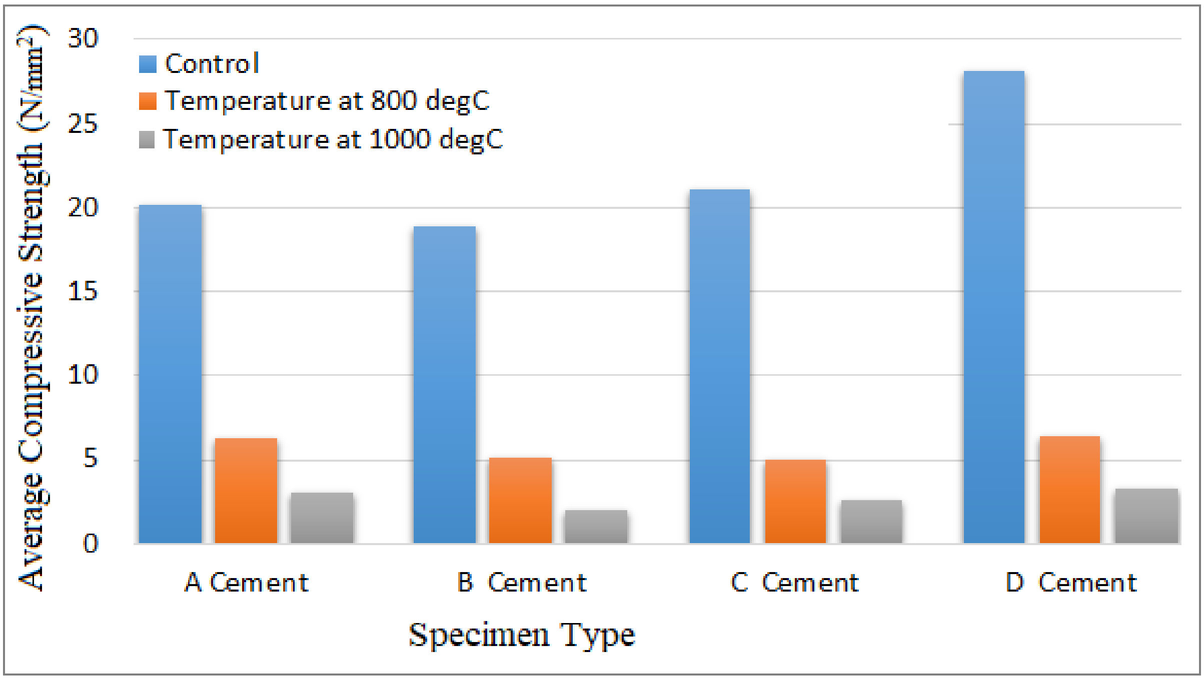


Figure 2: Control Compressive strength of hardened concrete specimen and those exposed to 800°C and 1000°C.

**Compressive Strength of Specimens Exposed to an Elevated Temperature of 1200°C**

For concrete specimen exposed to an elevated temperature of 1200°C, the entire concrete specimen melted (not shown). This therefore, justifies the claims of Naus (2006) which states that at above 1200° C and up to 1300° C, components of the concrete begin to melt and above the temperature say 1300°C to 1400°C concrete exists in the form of a melt.

## SUMMARY AND CONCLUSION

### Summary

This research is aimed at assessing the properties of concrete made with some selected brands of Nigerian cement exposed to elevated temperature In this study a number of tests were carried out so as examine the brand of cement that can withstand elevated temperature. The highlights of the major findings are summarized as follows:

i. The aggregate bulk density, specific gravity, aggregate moisture content and aggregate absorption capacity for fine and coarse aggregate were found to be 1660 kg/m$^3$ and 1680 kg/m$^3$, 2 and 2.68 , 0.18% and 2%, 3% and 1% respectively.
ii. The corse aggregate has an Aggregate impact value of 11.43% and an aggregate crushing values of 21.5%.
iii. The summation of elements found in cement A, B, C and D were 97.65%, 97.701%, 97.38% and 97.11% respectively. However, cement B has the highest percent of CaO (75.57%), lowest percent of $SiO_2$ (11.3%), lowest percent of $Al_2O_3$ (3.5%)
iv. Workability value for concrete made with different brands of cement A, B, C and D fell within the category of very low slump (0 – 25mm).
v. Concrete specimen for all brands of cement A, B, C and D has a compressive strength of 20.14 N/mm$^2$, 18.92 N/mm$^2$, 21.08 N/mm$^2$, 28.09 N/mm$^2$ while that exposed to 800$^o$C has a decrease in compressive strength of 6.27N/mm$^2$, 5.08N/mm$^2$, 5N/mm$^2$, 6.4N/mm$^2$ respectively.
vi. In terms of compressive strength of concrete specimen made with A, B, C and D cement exposed to 1000$^o$C after 28days curing, a decrease in compressive strength was recorded and the values obtained were 3.03N/mm$^2$, 1.97 N/mm$^2$, 2.57N/mm$^2$, 3.27 N/mm$^2$ . At 1200$^o$C, concrete specimen made with cement brands A, B, C and D disintegrated.

## Conclusion

After carrying out the experiments, observations, analysis and discussions on the properties of concrete made with some selected Nigerian brands of ordinary Portland cement exposed to elevated temperature, physical and mechanical properties fine and coarse aggregate was found to fall within the ranges of the various available standards.Chemical composition of all the brands of ordinary Portland cement used in this project is in line with ASTM C 150 (2005) requirement and the workability of the concrete specimen made with cement A, B, C and D is 17, 19, 15 and 18 respectively which is within limit of Building Research Establishment 1997, (0 – 25mm) slump.The average Compressive strength of concrete made with cement brand A, B, C and D when exposed to 800$^o$C and 1000$^o$C ranges between 5.0N/mm$^2$ to 6.4N/mm$^2$ and 1.97N/mm$^2$ to 3.27N/mm$^2$ respectively. While all the concrete specimen disintegrated when exposed to an elevated temperature of 1200$^o$C. We hereby recomment the following:

a) In areas where concrete is likely to be exposed to high elevated temperature not above 1000$^o$C, Cement brand D should be use.
b) Concrete specimen made with cement brands A, B, C and D should not be exposed to temperature above 1000$^o$C.
c) Blending of these brands of Portland cement with pozzolana (either natural or artificial) and exposing them to an elevated temperature of a maximum of 800$^o$C, but not higher than 1000$^o$C is recommended.

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