



## STRENGTH EVALUATION OF POZZOLANIC CONCRETE CONTAINING CALCINED CERAMIC WASTE AND GLASS WASTE POWDER

Arum, C. , Akande, S. P. and Alabi, S. A.

Department of Civil Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

Corresponding author: [carum@futa.edu.ng](mailto:carum@futa.edu.ng)

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### Abstract

The problems associated with the production of cement used for concrete such as emission of toxic gases, high energy demand, and natural resources consumption, all constitute adverse effects on ecology and the economy. However, utilization of finely-ground construction and demolition wastes such as ceramic tiles and glass waste to partially replace cement will help in mitigating the aforementioned problems. This is therefore a report of the findings of an experimental investigation on the strength property of concrete made by partial substitution of cement with Calcined Ceramic Waste (CCW) and Waste Glass Powder (WGP) at binary and ternary levels. A mix ratio of 1:2:4 by weight of the binder, sand, and granite with a water to cement ratio of 0.65 was adopted to produce concrete with characteristic cube strength of 15 N/mm<sup>2</sup>. Tests carried out include flowability potential of fresh concrete matrix and compressive strength. The results of tests carried out on mixes of different replacement levels of ordinary Portland cement (OPC) with CCW and WGP show that at maturity age of 90 days, concrete compressive strength decreased as the substitution level of CCW and WGP increased except at 5%CCW with 5%WGP (C<sub>5</sub>G<sub>5</sub>) and 5%CCW with 10%WGP (C<sub>5</sub>G<sub>10</sub>) replacements which gave strengths of 19.03 N/mm<sup>2</sup> and 19.00 N/mm<sup>2</sup> respectively. These values although less than 22.07 N/mm<sup>2</sup> which is the value of the control, nevertheless satisfy the minimum strength requirement for the concrete grade used. Therefore, in addition to providing concrete of usable quality while simultaneously reducing the amounts of Portland cement required, the pozzolanic concrete produced is also eco-friendly and will help reduce global green gas emission and promote sustainability of construction materials.

Keywords: Calcined ceramic waste, waste glass powder, pozzolanic concrete, compressive strength, workability.

### Introduction

The properties of construction materials dictate their fields of application. Strong, durable, and efficient buildings and installations may be erected only when the quality, that is, the properties of materials of the intended structures have been correctly evaluated. In many developing countries, Ordinary Portland cement (OPC) is expensive and often in short supply, a fact that has greatly hindered housing affordability (Abdullahi *et al.*, 2013). In addition, the continued growth in population witnessed over the years, especially since the twentieth century, has resulted in an increase in consumption of both man-made and natural resources which ultimately becomes an environmental concern. Concrete, the foundation of our infrastructure, is universally known for its structural capabilities and ease of use. It can form practically any shape imaginable for a wide range of applications by mixing appropriate proportions of commonly available materials such as cement, natural aggregates, and water (Ismail and Al-Hashmi, 2009). In order to obtain concrete of good quality, it is essential to select suitable materials, as well as the requisite concrete grade, especially when there will also be a partial replacement

of such materials to be used by other locally available materials (Wankhede and Fulari, 2014). In order to achieve strong and durable concrete, it is necessary to carefully proportion, mix and compact the ingredients (Dale *et al.*, 2009).

The cost of such construction materials as cement, sand, and aggregate keeps rising on a daily basis because of high demand which has culminated into a scarcity of these raw materials coupled with the skyrocketing cost of energy. In terms of reduction in energy cost and natural resources conservation, the utilization of alternative constituents for concrete presents a global interest (Safiuddin *et al.*, 2010). Alternative constituents are such that can substitute for cement, providing a good option to OPC often at a highly reduced cost and capable of making considerable inputs to the provision of affordable shelter (Abdullahi *et al.*, 2013; Nkumah and Lasisi, 2018). Verma *et al.* (2017) conducted research on the applicability of powdered sanitary ware wastes to partially replace cement in concrete. Safe application of ceramic wastes is possible without the need for radical alteration in the production process. In the same

vein, Arum and Mark (2014) in a research conducted on the utilization of granulated cupola slag to partially substitute OPC, showed that within the OPC substitution range investigated, the compressive strength of concrete continuously increased across all curing ages as the percentage of substitution increased, attaining a maximum compressive strength increase of 31.9% in comparison to that of the reference concrete. This delivers a two-fold benefit of savings in the cost of depositing the waste in landfills as well as conservation of raw materials and natural resources, which effectively translate to cost savings and environmental protection. Production of cement involves high amount of energy input (850 kcal per kg of clinker) while 0.55 tonne of chemical CO<sub>2</sub> and an additional 0.39 tonne of CO<sub>2</sub> in the form of fuel emissions are generated for every tonne of cement produced, which together amount to 0.94 tonnes of CO<sub>2</sub>. Therefore, using materials such as ceramic waste powder to substitute cement in concrete translates to substantial energy saving as well as provides environmental benefits (Pacheco-Torgal and Jalali, 2009). Babatola and Arum (2020) in a research carried out on the evaluation of the compressive strength of concrete containing binary cement and ternary aggregates, established that although an increase in the ceramic waste powder content causes an overall decrease in the compressive strength of the concrete, at 5% replacement level, compressive strength of 16.6 N/mm<sup>2</sup> was obtained, which is comparable to the reference concrete and falls within acceptable limit for the concrete grade considered in that research. In addition, production of concrete containing suitable blends of milled glass waste and OPC, is potentially a milestone in the evolution of infrastructure systems that are economical, energy-efficient and environmentally friendly (Mageswari and Vidivelli, 2010; Khan *et al.*, 2020). Corroborating other researchers, Khan *et al.* (2020) made a case for waste sheet glass powder as a supplementary cementitious material for producing concrete. Glass waste with particle size less than 45 µm combined with concrete at cement binder replacement levels of 10-40% offers a significant improvement on the mechanical and durability properties of the concrete (Sadiq and Atoyebi, 2015; Olofinnade *et al.*, 2017; Manganji *et al.*, 2020). This research, therefore, seeks to assess the compressive strength of pozzolanic concrete produced by using binary and ternary blends of CCW and GWP to partially replace OPC.

## Experimental Sequence

### Materials Used

The materials employed were ordinary Portland cement (OPC), calcined ceramic waste (CCW), waste glass powder (WGP), sand, crushed granite (CG), and water. The OPC used was obtained locally within Akure Metropolis, Southwestern Nigeria. It was

ensured that the cement was held in an airtight plastic container. The OPC of grade CEM 1 42.5R was employed. OPC is the most commonly used cement. Different brands of OPC are produced in Nigeria such as Dangote, Elephant, and Lafarge but for this research, Dangote cement was used being the most commonly used and adjudged reliable. Fineness and Setting time tests were conducted on the cement in accordance with BS 1881-131:1998, to ascertain its suitability. The waste glass (WG) and ceramic waste (CW) were obtained from a dumpsite within Akure Metropolis, Southwestern Nigeria. The CCW and WGP were transported to the Structural Engineering laboratory of the Department of Civil Engineering where they were dusted and isolated to remove visible earth impurities. Thereafter, they were pulverized to less than 4 mm diameter before being ball-milled to achieve powdered granulated form. The final process involved sieving through 75 µm before using it to partially substitute cement in the production of pozzolanic concrete. Calcination of ceramic powder is the process whereby ceramic powder is fired at a sufficiently high temperature such as 600°C in a furnace for about two hours so as to destroy the plasticity but not high enough to sinter it. Simply put, calcining is the firing of ceramic material to create a powder of new physical properties. It is often carried out to kill the plasticity or burn away the hydrates, carbonates, sulfates of clay, or refracting material. The chemical composition of the OPC, CCW, and WGP was analyzed using X-ray fluorescence (XRF). The sand and crushed granite aggregates were also acquired in the Akure metropolis and processed to conform to the recommendation of BS EN 933-11, (2009). The aggregates were washed and screened, to eliminate deleterious materials in accordance with the requirements of BS 882, (1997). The aggregates were ensured to meet the medium grading zone criteria (BS EN 933-1, 1997). The coarse aggregate had a maximum size of 12.5 mm, while the fine aggregate had a maximum size of 4.75 mm. The composition of the fine aggregate (i.e., sand) and crushed granite (coarse aggregate) used in the investigation is represented in Figure 1. Table 1 summarizes the physical characteristics of the binders and aggregates. The sand used had a well-graded distribution and was suitable for concrete production. Aggregates' specific gravity should be between 2.30 and 2.90, according to ACI, (2007). Thus, at a specific gravity of 2.73 for sand

and 2.68 for crushed granite (coarse) aggregate, the values for specific gravity of both fine and coarse

aggregates, are within the acceptable range, making them ideal for use in concrete. The quality of the water used in the mix was such that the chemical reaction

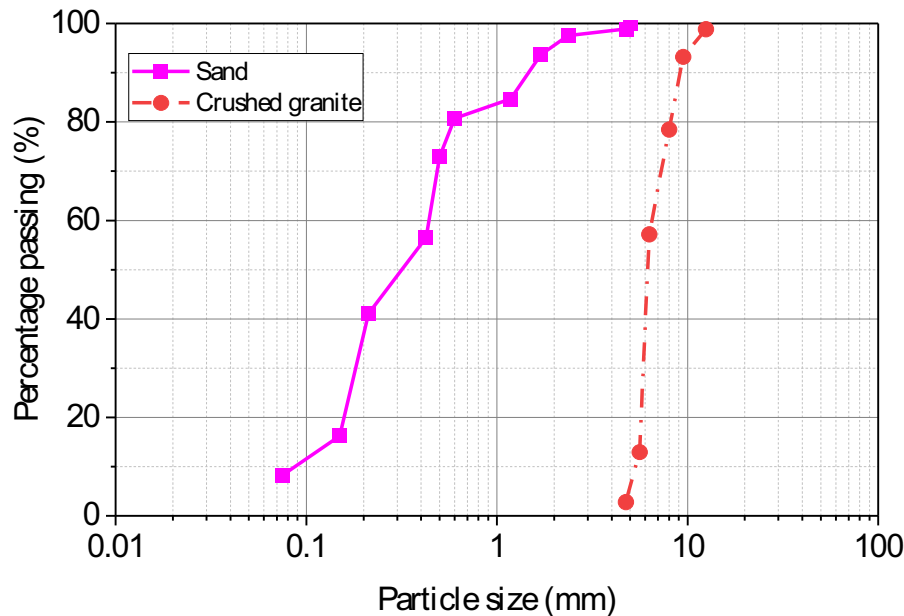


Figure 1: Particle gradation of sand and crushed granite

Table 1: Physical Properties of Aggregates and Binders

| Physical properties         | Binding materials |      |      | Aggregates |                 |
|-----------------------------|-------------------|------|------|------------|-----------------|
|                             | OPC               | CCW  | WGP  | Sand       | Crushed granite |
| Moisture content (%)        | -                 | -    | -    | 1.53       | -               |
| Fineness modulus (%)        | 99.7              | 100  | 100  | -          | -               |
| C <sub>u</sub>              | -                 | -    | -    | 3.78       | -               |
| C <sub>c</sub>              | -                 | -    | -    | 2.56       | -               |
| Specific gravity            | 3.09              | 2.63 | 2.57 | 2.73       | 2.68            |
| Shape                       | -                 | -    | -    | -          | Angular         |
| ACV (%)                     | -                 | -    | -    | -          | 29.75           |
| AIV (%)                     | -                 | -    | -    | -          | 21.03           |
| Water absorption (%)        | -                 | -    | -    | 0.55       | -               |
| Maximum aggregate size (mm) | -                 | -    | -    | 4.75       | 19.00           |
| Silt/Clay content (%)       | -                 | -    | -    | 4.76       | -               |

### Concrete Mix Design and Testing

Table 2 presents the concrete mixture proportions. The concrete mixture proportions show the control mixture, concrete mixtures with CCW substituting OPC, WGP replacing OPC, and mixtures containing both CCW and WGP as a partial replacement of OPC. Both the CCW and WGP were replaced with OPC at varying replacement levels ranging from 5 to 20%. On the mixture ID column of Table 2, the letter 'C' denotes the CCW, and 'G' is the WGP. For suitable workability, a water to cement ratio of 0.65 was assumed in the absence of a superplasticizer. Twelve (12) mixes were

developed (see Table 2) and tested to evaluate the workability and compressive strength. A mix ratio of 1:2:4 by volume of the binder, sand, and crushed granite with a water to cement ratio of 0.65 was used to cast concrete specimens containing varying proportions of CCW and WGP as cement replacement for target strength of 15 N/mm<sup>2</sup> (C15 concrete grade). The aggregates were batched by volume using the stated mix proportions in Table 2 before mixing together thoroughly following the recommendations of BS 1881 part 125 (2013) and BS EN 206 (2013). After thoroughly mixing the concrete constituents, the

slump of each mixture was measured to assess its workability before placement in the required moulds according to BS EN, 12350-2 (2019). After mixing, the fresh concrete was poured into 150 mm × 150 mm × 150 mm standard steel moulds, which had been lubricated with engine oil to ensure easy demoulding and smooth surface. The compaction was done in 3 layers to achieve adequate compaction of the specimen. The casting was carried out per the requirement of BS EN, 12390-2 (2019). The specimens were allowed to set for 24 hours before demoulding and immersion in a pool of potable water in a tank for ages 28 and 90 days to allow for effective curing. The major test carried out to check the strength property of the cubes was the compressive strength. The compressive strength test was carried out using a Universal Compression Loading Machine of capacity 1000 kN on the concrete cubes in accordance to BS 1881: Part 119:1983. The cubes were weighed and thereafter placed in the Universal compression testing machine such that the plates were positioned at the top and bottom of the sample to ensure uniform load distribution. The cube was loaded centrally and the readings were taken until there was no further progressive reading on the digital load and strength display screen gauge. The compressive strength was then calculated for each cube sample using Eq. 1.

$$f_{cc} = \frac{F}{A} \quad (1)$$

where,  $f_{cc}$  is the compressive cube strength, in N/mm<sup>2</sup>, F is the crushing load, in N, A is the net area of cubes, in mm<sup>2</sup>.

Table 2: Experimental mix design proportion ‘ for the concrete cubes

| Mixture ID                      | Binding Materials (%) |     |     | Aggregates (%) |                 |
|---------------------------------|-----------------------|-----|-----|----------------|-----------------|
|                                 | OPC                   | CCW | WGP | Sand           | Crushed granite |
| Control                         | 100                   | -   | -   |                |                 |
| C <sub>5</sub>                  | 95                    | 5   | -   |                |                 |
| G <sub>5</sub>                  | 95                    | -   | 5   |                |                 |
| C <sub>5</sub> G <sub>5</sub>   | 90                    | 5   | 5   |                |                 |
| C <sub>10</sub> G <sub>5</sub>  | 85                    | 10  | 5   |                |                 |
| C <sub>5</sub> G <sub>10</sub>  | 85                    | 5   | 10  | 100            | 100             |
| C <sub>10</sub> G <sub>10</sub> | 80                    | 10  | 10  |                |                 |
| C <sub>15</sub> G <sub>10</sub> | 75                    | 15  | 10  |                |                 |
| C <sub>10</sub> G <sub>15</sub> | 75                    | 10  | 15  |                |                 |
| C <sub>15</sub> G <sub>15</sub> | 70                    | 15  | 15  |                |                 |
| C <sub>20</sub> G <sub>15</sub> | 65                    | 20  | 15  |                |                 |
| C <sub>15</sub> G <sub>20</sub> | 65                    | 15  | 20  |                |                 |

## Results and Discussion

### Fineness, Setting Time, and Soundness Tests of Binders

Figures 2 to 4 present the outcome of fineness, setting time, and soundness tests on the different mix proportions of binders. According to BS EN 196-6-2010, good cement should have fineness less than 10%; in other words, the weight of the residue retained on the sieve should not exceed 10%. Also, the initial

time at which good OPC paste losses its plasticity should not be more than 30 minutes while its final setting time should not be more than 10 hours. According to BS EN 196-3-2005, the soundness of OPC, which is measured by its expansion, is limited to 10 mm. Any value above this shows a deformity in the constituent particles of the cement. Figures 2 to 4 show that the binders used in this study met all the requirements on fineness, setting time, and soundness in accordance with relevant BS codes.

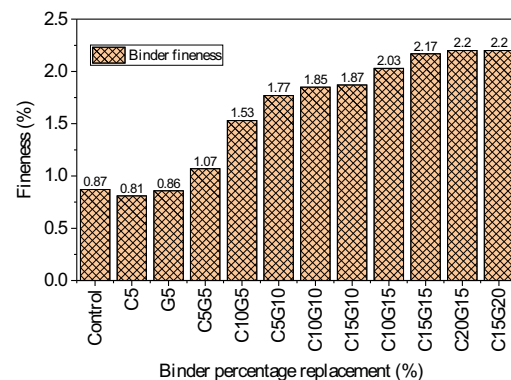


Figure 2: Fineness test result of the different binders

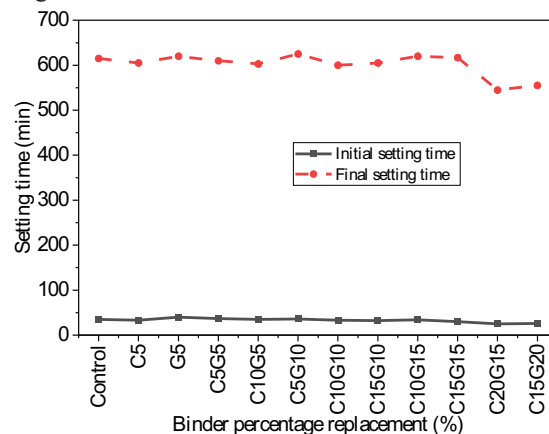


Figure 3: Setting time test result of the binders

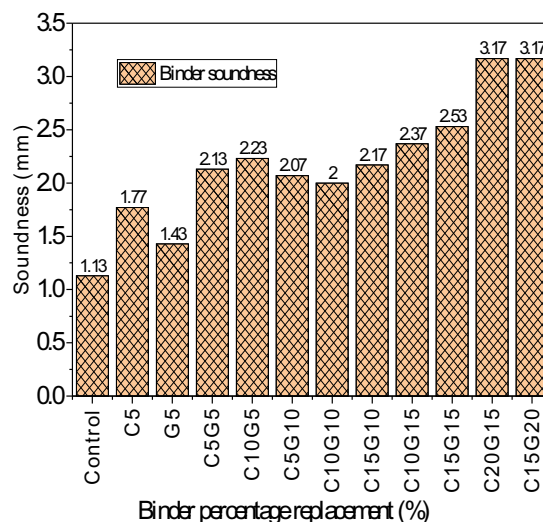


Figure 4: Soundness test result of the binders

### Chemical Composition of Binders

The results of the chemical composition of the OPC, CCW, and WGP are given in Table 3. This is done to ascertain the most dominant oxide in the binding agents and to confirm their conformity with the manufacturer's specified standard. The result obtained

for cement shows that calcium oxide gives the highest percentage with 89.49%, followed by silicon oxide with 4.23% and then Sulfate oxide with 2.23%. This result is expected, as the decomposition of limestone composed mainly of  $\text{CaCO}_3$  disintegrates to form the main reactant oxide and other minor by-products.

**Table 3: Oxide Composition of the binders**

| Oxide composition | CaO   | SiO <sub>2</sub> | Fe <sub>2</sub> O <sub>3</sub> | Al <sub>2</sub> O <sub>3</sub> | SO <sub>3</sub> | SnO <sub>2</sub> | Sb <sub>2</sub> O <sub>3</sub> | K <sub>2</sub> O | MgO  |
|-------------------|-------|------------------|--------------------------------|--------------------------------|-----------------|------------------|--------------------------------|------------------|------|
| Cement (%)        | 89.49 | 4.22             | 1.14                           | 1.30                           | 2.23            | 0.33             | 0.39                           | -                | -    |
| CCW (%)           | 0.54  | 64.79            | 4.44                           | 19.25                          | 0.84            | 1.99             | 1.89                           | 4.36             | -    |
| WGP (%)           | 18.63 | 70.78            | 0.77                           | 3.73                           | 1.16            | 1.84             | 1.65                           | 0.33             | 0.40 |

### Slump Test

The slump test was done in accordance with British Standards (BS EN 12350-2:2019). The result for the slump test of all the replacement levels and the corresponding slump exhibited by each is given in Figure 5. From the result, four replacement levels indicated as C<sub>0</sub>, C<sub>5</sub>, G<sub>5</sub>, and C<sub>5</sub>G<sub>10</sub> exhibited true slump (indicating uniform drop of the concrete mass without disintegration) while the remaining eight replacement

levels all show shear slump (which is an indication of lack cohesion of the concrete which may cause them to undergo segregation and bleeding) and this sign is an undesirable property for the concrete durability. A collapse slump was not recorded for the concrete mix at any replacement level. Also, nearly all the slump values fall within the recommended values established for mass concrete structures and pavements as they are between 20 mm to 50 mm.

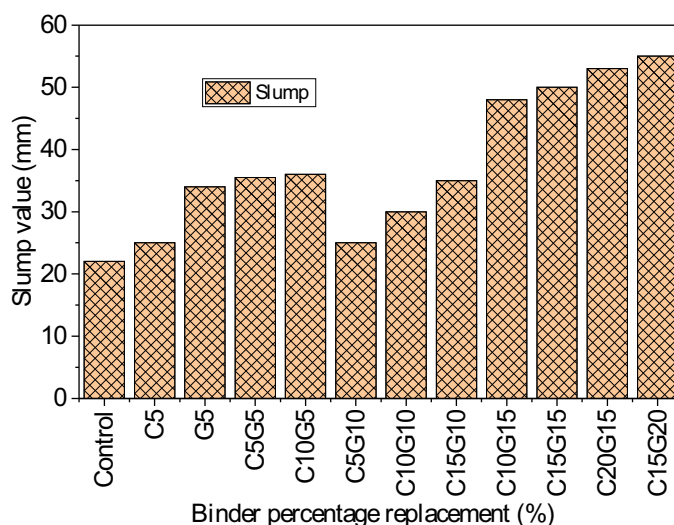


Figure 5: Slump values for the concrete mixtures.

### Compressive Strength

The compressive strength of the concrete cubes was tested to ensure that the concrete mixture meets the specified strength for the work at hand. These results are often utilized for quality control, acceptance of concrete, and for its strength estimation in a structure, and also for ensuring that the curing and protection given a structure are adequate. The combined effects of Calcined Ceramic Waste (CCW) and Waste Glass Powder (WGP) for partial substitution of OPC on the compressive strength development at 28 and 90 days of curing are shown in Fig. 6 for the various concrete

mixtures. Generally, there is a continuous increase in compressive strength as the curing age increases, but a gradual decrease in the compressive strength as the percentage replacement increases. The incorporation of a combination of 5%CCW and 10%GWP shows only a sharp increase in the compressive strength at 28 and 90 days, although the value is somewhat less than that of the reference concrete. This could be attributed to the fact that WGP had a better hydraulic reaction than CCW given the fact that the SiO<sub>2</sub> and CaO contents are higher in WGP than in CCW (see Table 3). The microfilling ability of WGP could have contributed to strength development.

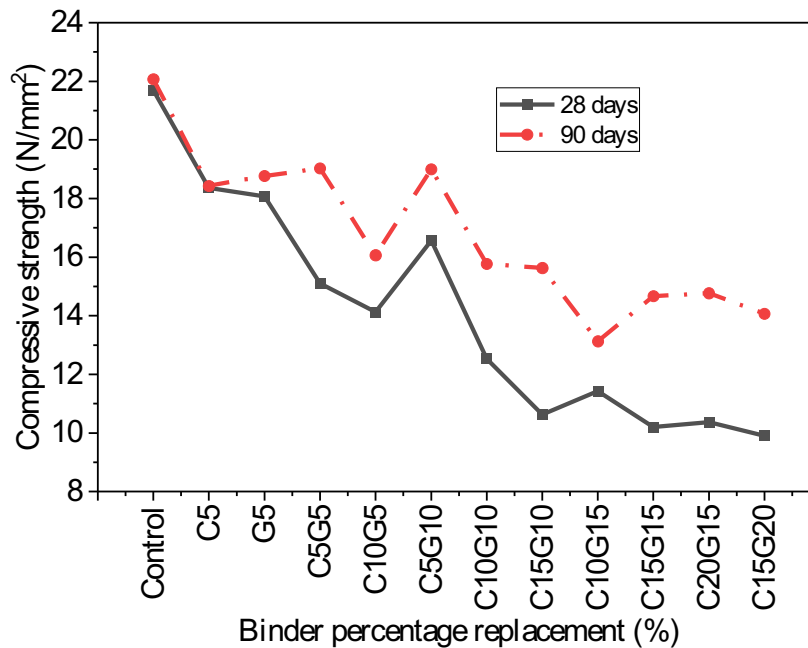


Figure 6: 28 Days and 90 Days Concrete Compressive Strength Chart

### Conclusions

In conclusion, the strength of concrete containing 100% Ordinary Portland Cement is greater than that of concrete made with calcined ceramic waste and waste glass powder. Also, the concrete made with 5% Calcined Ceramic Waste and 5% Waste Glass Powder has a compressive strength of 19.03N/mm<sup>2</sup> and that of 5% Calcined Ceramic Waste and 10% Waste Glass Powder has a compressive strength of 19.00 N/mm<sup>2</sup>. Both values satisfy the strength requirement for concrete designed to have a characteristic strength of 15 N/mm<sup>2</sup>.

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