# EFFECT OF PULVERIZED GLASS POWDER ON THE COMPRESSIVE STRENGTH OF REVIBRATED CONCRETE


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## ABSTRACT

*Experimental study on the Effect of pulverized glass powder (PGP) on the compressive strength of re-vibrated concrete is presented. Concrete mix of 1:2:4 was used to prepare a total of forty-eight fresh concrete cubes specimen: sixteen for control with 0% PGP; thirty-two cubes for the different percentages of OPC replacements (10%, 20%, 30% and 40% PGP). Each set of fresh concrete cubes were subjected to initial vibration and then re-vibrated at an interval of 10 minutes successions up till 1 hour. The compressive strength was determined at 7 and 28days curing age for each concrete cube. The results show that maximum compressive strength were best achieved in three categories: 21.39 N/mm² for non-revibrated; 23.64 N/mm² and 18.34N/mm² for 0% and 20% PGP revibrated concrete respectively. It is concluded that pulverized glass can be blended with cement up to 20% PGP to achieve a substantial compressive strength of revibrated concrete.*



## KEYWORDS

*Pulverised glass powder, revibrated concrete, compressive strength, cement, percentage replacements.*


## 1. INTRODUCTION

Infrastructural development is the number one priority in the world especially in developing countries like Nigeria. Achieving it has been threatened by hikes in the price of conventional building materials including the great binder, cement, which is one of the major ingredients used in concrete production. This has inevitably put inflationary pressure on the economy as construction material becomes more expensive [1].

Glass powder according to Dhanaraj *et al*. [2] is a transparent material produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling during which solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing. The amount of waste glass is gradually increased over the recent years due to an ever-growing use of glass products. Most waste glasses have been dumped into landfill sites. The land filling of waste glasses is undesirable because they are not biodegradable, which makes them environmentally less friendly. The waste glass in concrete to become the construction economical as well as creating eco-friendly environment.

Roz-Ud-Din and Parviz [3]in their report concluded that when glass is incorporated as a partial replacement for cement in concrete, it is estimated to undergo pozzolanic reaction that results in improved microstructure of recycled aggregate concrete. Significant increase in the later age strength is achieved through the formation of denser and less permeable microstructure which is expected to be the result of the filling effect of the sub-micron sized glass particles used. Rahman and Uddin [4] recommended better result for compressive strength, when the percentages of glass powder was 20%. Chen *et al*. [5] established that when glass was crushed to a particle size finer than 75µm, concrete specimens were found to achieve prolonged compressive strength development, which can be attributed to the pozzolanic nature of very fine glass powder. Shayan *et al.* [6] carried out a research to evaluate the incorporation of glass sand powder to replace natural sand and cement respectively. They noticed a pozzolanic reaction of glass with cement that contributed to the development of compressive strength.

Revibration of concrete results in improved compressive and bond strength, reduction of honey-comb, reduction in shrinkage and creep, release of water trapped under horizontal reinforcing bars and removal of air and water pockets if properly executed [7, 8]. Revibration is most effective at the lapse of maximum time after the initial vibration, provided the concrete is sufficiently plastic to allow the vibrator to sink under its own weight into the concrete and make it momentarily plastic. When revibration occurs after the initial set, it breaks down some of the calcium hydroxide that has already been formed, which allows freshly placed concrete adjacent to the revibrated concrete to join with it, rather than introducing a construction joint and it again becomes a monolithic concrete structure [7, 9]. The percentage increase in compressive strength increases with the time lag interval of revibration up to certain time lag interval depending on the mix and water cement ratio and thereafter, decreases. The increase may be due to re-arrangement of coarse aggregate and mortar in the concrete under the plastic condition.

In this study, the aspect of revibrating fresh concrete prepared from pulverised glass powder (PGP) as a partial substitute of cement is primarily being investigated to evaluate the impact on the compressive strength of the hardened concrete.

## 2. Materials And Methods

### 2.1. Materials

The materials used for this study are: ordinary Portland cement (OPC), river sand (Fine aggregate), granite chippings (coarse aggregates) with maximum 20mm size, water and pulverised glass powder (PGP).

### 2.2.1. Ordinary Portland Cement (OPC)

The OPC used as a binder throughout this study is a type 1 ordinary Portland cement (general purpose Portland cement suitable for most uses in constructions) and conforming to BS 12 [10]. This OPC was procured in Minna city of Niger State.

### 2.2.2. Fine aggregate (sand)

The sand (fine aggregate) was sourced from Kpankugu, a suburb of Minna environs of Niger state, Nigeria. It was free from impurities and organic matters, this was prepared and sun dried to conforms to the specifications in BS 882 [11].

### 2.2.3 Coarse aggregate (granite chippings)

The coarse aggregates were collected from a dealer of quarry products in Kpakungu which was prepared and used in this research study. Their sizes were not more than 20mm.

### 2.2.4 Water

The water used for mixing the materials was obtained from borehole which is in accordance with BS 3148 [12] requirements making the water fit for drinking, free from suspended particles, organic materials and soap which might adversely affect hydration of cement.

### 2.2.5 Pulverised glass powder (PGP)

The glasses which were collected from some aluminium workshops in Minna metropolis. Theses glasses were prepared, pounded and then milled to particle sizes passing through sieve 75μm (Fig. 1).

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Figure 1. Pulverished glass powder (PGP)

## 2.2. Methods

Among experimental tests carried out were: the chemical analysis of the pulverised glass powder, aggregate characterization which includes bulk density, sieve analysis (particle size analysis), specific gravity and moisture content; slump of fresh concrete; and compressive strength of hardened revibrated concrete.

### 2.2.1. Particle size distribution

Sieve analysis is simply described as the process of separating a sample of aggregate into fractions of same particle sizes. Each fraction possesses particles within specific limit, these being the openings of the standard sieves. The sieves are mounted in frame so that they are placed in descending order with the largest at the top and the smallest at the bottom. The particle size analysis was carried out to determine the grading of the aggregates in accordance with BS 1377 part 2 [13] and the results are presented in figures 1, 2 and table 1. This was achieved by plotting the grain size curve of the aggregates and the determination of the Uniformity coefficient (Cu) together with the Coefficient of curvature (Cc).

### 2.2.2. Specific gravity of aggregates

Specific gravity is the fundamental physical characteristic of a material. In accordance with ASTMC 127-15[14], specific gravity is the ratio of mass of a unit volume of material to the mass of same volume of water at the same temperature. The result is presented on table 2.

### 2.2.3. Bulk density

Bulk density is defined as the actual mass of the sample that would fill a container of unit volume and this density is use to convert quantities by mass to quantity by volume. Density depends on how densely the aggregate are packed and at the same time on the size distribution of the particles. Thus, the degree of compaction was specified by ASTM C29-C29M-17 [15] which recognizes two degree: loose (uncompacted) and compacted. The result is presented on table 3.

### 2.2.3. Moisture content

The measure of the ratio of weight of water to the weight of sample in percentage is known as the moisture content of that sample. It can also be defined as the water in excess of the saturated and surface dry condition. Thus; the total water content of a moist aggregate is equal to the sum of absorption and moisture content.

## 2.3. Fresh Concrete

Concrete mix design can be defined as the selection of the most suitable materials i.e. binding materials (cements and glass powder), water, and various aggregate to produce concrete having the desired properties. The three properties for which the concrete is designed according to Neville [16] are the degree of workability, density and compressive strength. For the purpose of this research work, mix design by absolute volume method was used to proportion the constituent materials. A concrete mix of ratio 1:2:4 was adopted for the production of concrete cubes at water / cement ratio of 0.55.

### 2.3. 1. Production of non-revibrated and revibrated concrete cubes

Forty-eight (48) concrete cubes specimen of metal mould size 150mm × 150mm × 150mm was produced for this study. Batching and casting of the concrete cubes was carried out in accordance BS 1881 Part 108 [17] with mix ratio of 1:2:4 and constant water cement ratio of 0.55. The mix design was used to select the required proportion of the constituent materials which include cement, glass powder, water and aggregate to produce concrete that satisfy the requirements of strength, workability and durability. The concrete cubes were prepared for two procedures, revibrated and non-revibrated. Eight (8) non-revibrated and forty (40) revibrated concrete cubes.

For the non-revibrated, eight (8) cubes were produced in total. For the revibrated, Four (4) concrete cubes (control cubes) were produced with pure cement and another four (4) cubes were produced each using 10%, 20%, 30% and 40% glass powder replacement for cement respectively. All the forty (40) cubes were revibrated for 60 seconds at 10 minutes interval to duration of 1 hour.

### 2.3. 2. Slump test

This test is used for the determination of the workability of fresh concrete. It is usually undertaken at the point of delivery to ensure that the concrete is in adequate consistency for placement. The mould of slump test is a frustum of a cone 30.5mm in height and base 20.3mm in diameter. This test was carried out in accordance with B.S 1881: part 102 [18] and the result is presented on table 4.

### 2.3.3. Density cured concrete cubes

Density of concrete was determined after the 7th and 28th days of curing. The concrete cubes will be removed from the curing tank and allowed to dry for 3 minutes; weight and density of each cube will then be determined. The result is presented in figure 4.

### 2.3. 1. Compressive strength test of concrete cubes

Compressive strength is the capacity of a material or structure to withstand axially directed pushing forces. It is also defined as the maximum compressive load a concrete can carry per unit area. It was carried out to determine maximum compressive strength of concrete cubes after 7th and 28th days of curing. This test was carried out based on the specification in BS 1881: Part 116 [19]. The result is presented table 5 and figure 5.

## 3. Results and Discussions

### 3.1. Particle Size Distribution of Aggregates

The result in Figure 4.1 shows the distribution curve of fine aggregate, about 500g of fine aggregate was measured for the analysis. The curve shows that 94.75% of the sample passed through the 5mm British sieve size while 5.25% was retained, thus indicating that nearly more than 50% passed through the sieve size.  Therefore, the aggregate is a fine graded soil (sand).

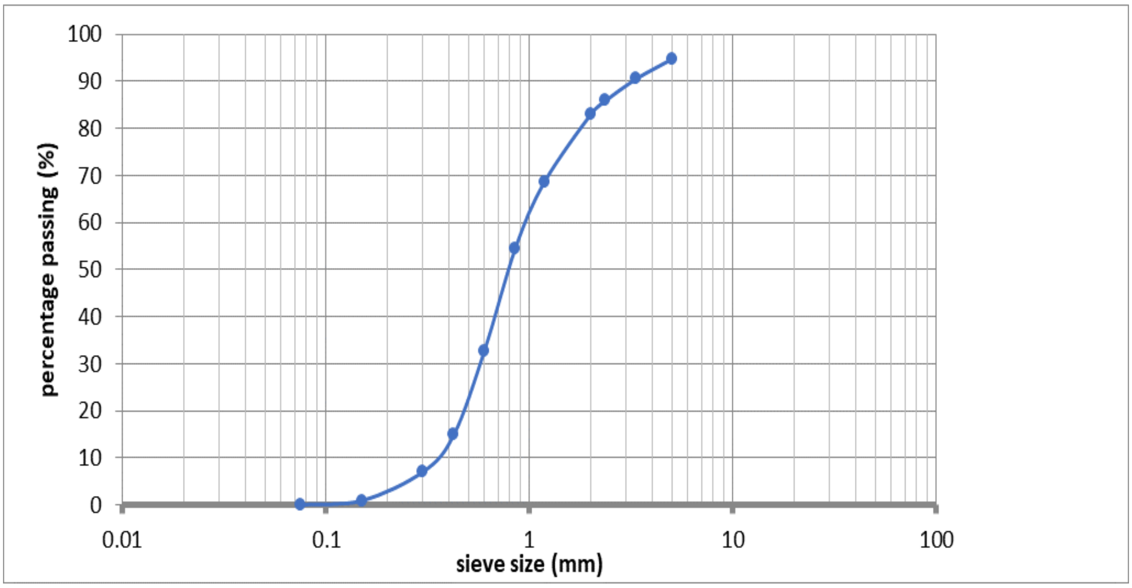


Figure 2. Particle size distribution of fine aggregate

Figure 3 shows the distribution curve of coarse aggregate, about 2kg of coarse aggregate was used for the analysis. The distribution curve shows that about 71% of the sample was retained on the 10mm sieve, thus indicating that majority size is 10mm.

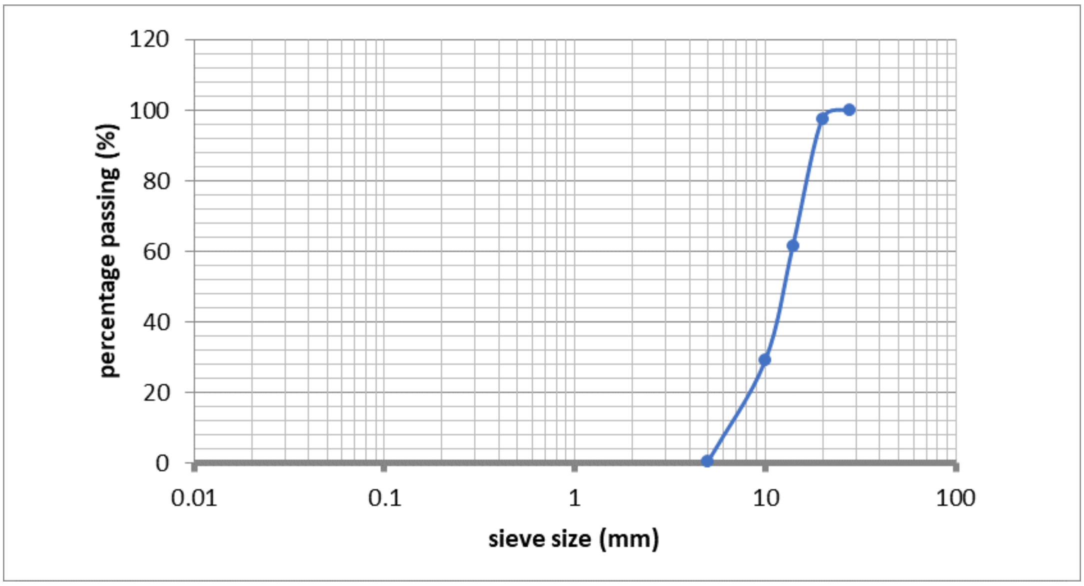


Figure 3. Particle size distribution of coarse aggregate

Table 1 shows the particle size analysis of pulverized glass. About 200g of the glass was measured for the analysis. The Fineness modulus (FM) of PGP calculated from Table 1 is 0.23, therefore, the pulverized glass is finer than fine aggregate [11].

Table 1. Particle size distribution of PGP.

| **Sieve size (mm)** | **Sample weight retained (g)** | **Percentage retained (%)** | **Cumulative percentage retained (%)** | **Cumulative percentage passing (%)** |
|---|---|---|---|---|
| 0.850 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.600 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.425 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.300 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.150 | 12.60 | 6.52 | 6.52 | 93.48 |
| 0.075 | 18.50 | 9.57 | 16.09 | 83.91 |
| Pan | 162.2 | 83.91 | - | - |
| Total | | | 22.61 | |

### 3.2. Oxide Composition of PGP

The chemical oxide results reflected that PGP is a very good pozzolana with silicon oxide ($SiO_2$= 72.668%), Aluminum oxide ($Al_2O_3$= 1.702%) and iron oxide ($Fe_2O_3$= 0.634%) constituting a total of 75% of pozzolanic material above the 70%.

### 3.3. Specific Gravity of Aggregates and PGP

The specific gravity results presented on table 2 shows that the specific gravity value for the PGP is 2.41 over an average of two trials. The fine aggregate has a specific gravity value of 2.54 and that of coarse aggregate was found to be 2.64 from the average of two trials. These values attained are in line with the BS requirement of 2.6 - 3.0 for fine aggregate and 2.4 - 2.8 for coarse aggregate. The specific gravity value of PGP was found to be less than the value for cement, 3.15.

Table 2. Specific gravity of aggregates and PGP

| **Material** | **Specific gravity** |
|---|---|
| Fine aggregate (Sand) | 2.54 |
| Coarse aggregate | 2.64 |
| Pulverised glass | 2.41 |

### 3.4. Bulk Density of Aggregate and PGP

The results of bulk density of aggregate (fine and coarse) and pulverized glass are presented in table 3. From the table 3, the values for compacted and un-compacted bulk density of pulverized glass are 990kg/m$^3$ and 1270kg/m$^3$. The results of bulk density depend on how the sample of milled are closely packed. The looseness, lightness in weight of pozzolanic materials makes them not closely packed thereby leading to low coherent bulk density. Also, the compacted and un-compacted bulk density of the fine aggregate (sand) are 1440kg/m$^3$ and 1590kg/m$^3$ while that of coarse aggregate (gravel) are 1461kg/m$^3$ and 1693kg/m$^3$ which correspond to the range of 1200-1800kg/m$^3$ for fine and coarse aggregates.

Table 3. Bulk density of aggregates and PGP.

| **Material** | **Uncompacted (Kg/m$^3$)** | **Compacted (Kg/m$^3$)** |
|---|---|---|
| Fine aggregate(sand) | 1440 | 1590 |
| Coarse aggregate(gravel) | 1461 | 1693 |
| Pulverised glass | 990 | 1270 |

### 3.5. Slump of Fresh Concrete

The results of slump test for the concrete cubes containing the glass powder are shown in table 4. The slump measures the workability of fresh concrete, the difference in height between the standard cone and the height of concrete after slump gives the slump value. It was observed from the slump test result that the slump value reduces as the glass powder content increases in the mix from 0% to 40%, the difference in slump value when cement is partially replaced with glass shows the demand of water, thus resulting in lower workability. Nevertheless, it can be concluded that to achieve the required workability, mixes containing pulverised glass will require higher water content than the equivalent normal mixes.

Table 4. Slump of Fresh concrete.

| **Percentage replacement (%)** | **Slump (mm)** | **Workability** |
|---|---|---|
| 0 | 48 | Low |
| 10 | 44 | Low |
| 20 | 36 | Low |
| 30 | 33 | Low |
| 40 | 32 | Low |

### 3.6. Compressive Strength of Hardened Concrete

#### 3.6.1 Density

The mean density of the hardened concrete cube at the end of 7 and 28 days' curing are given in figure 4. The density of all the concrete cubes cast fell within the range of 2200kg/m$^3$ to 2600kg/m$^3$. The result of the density displays that the density reduces as the percentage milled glass increases. However, the density increases as the curing days increase and as the concrete cubes become denser except for the 30 and 40 percentage increment which were found to be lower than the 7th day curing age result. This reduction can be attributed to the high silicon oxide (72.67%) and low calcium oxide contents of the PGP.

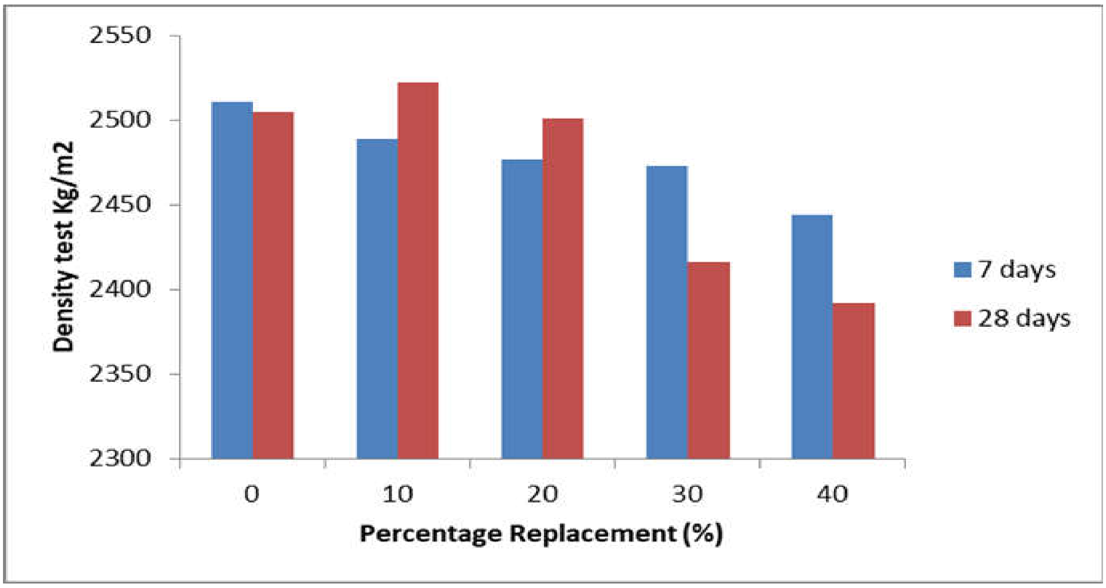


Figure 4. Effect of PGP on the density of concrete at different curing age.

### 3.6.2. Compressive strength of concrete and effect of percentage replacement of PGP

The compressive strength of concrete containing pulverised glass and the effect of revibration on the concrete cubes were investigated after curing period of 7 and 28 days respectively. The result is presented on table 5 and figure 5.

Table 5. Compressive strength of PGP revibrated concrete.

| **Item** | **Compressive strength of concrete (N/mm$^2$)** | | | | | | **Total Cube cast** |
|---|---|---|---|---|---|---|---|
| Form of vibration | Non-revibrated | Revibrated | | | | | |
| % replacement of cement for PGP | 0 | 0 | 10 | 20 | 30 | 40 | |
| 7 days curing | 18.68 | 20.20 | 16.04 | 14.87 | 10.27 | 9.09 | 24 |
| 28 days curing | 21.39 | 23.64 | 17.96 | 18.34 | 14.29 | 12.49 | 24 |
| Total cubes cast | 8 | 8 | 8 | 8 | 8 | 8 | 48 |

The result of the compressive strength tests on concrete cubes containing pulverized glass are shown in Table 2 and Figure 2. It can be seen from Table 2, that for the control concrete cubes (0%), the compressive strength increased from 18.69N/mm$^2$ at 7 days to 21.39N/mm$^2$ at 28 days for the non-revibrated cubes and from 20.20N/mm$^2$ at 7 days to 23.64N/mm$^2$ at 28 days for the revibrated cubes, thus indicating the strength developed at 28 days falls under grade 20 concrete.

It can generally be observed that concrete cubes containing PGP reflected lower compressive strength values of 16.04 N/mm$^2$ – 9.09 N/mm$^2$ and 23.64N/mm$^2$ – 12.49N/mm$^2$ for 7 and 28 days respectively. These indicate that the compressive strength reduces with PGP percentage replacements. Nevertheless, the compressive strength increases as the number of days of curing increases for each PGP percentage replacement.

The optimum percentage replacement at 20% with a compressive strength value of 18.34N/mm$^2$ after a curing period of 28 days. This is in agreement with what was obtained by Rahman and Uddin [4]. This strength developed at 28 days correspond to that of grade 15 concrete, thus indicating that it can be used for reinforced concrete with lightweight aggregate.

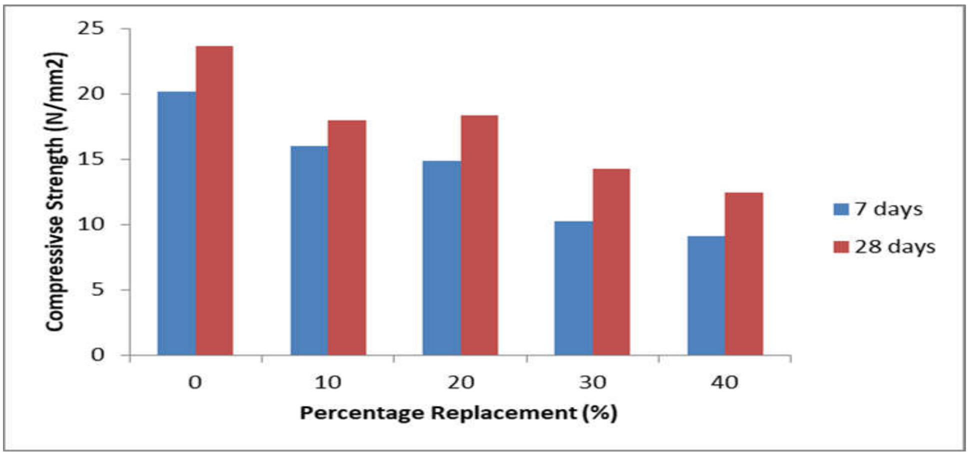


Figure 5. Effect of percentage replacement for PGP on the compressive strength of revibrated concrete

It is important to also notice from table 2, the effect of revibration as reflected by the result. The compressive strength of non-revibrated concrete (21.39 N/mm$^2$) is quite lower than that obtained from the revibrated concrete (23.64 N/mm$^2$). This also affirming the report of Krishna *et al.* [7] and Auta *et al.*, [8] that revibration do have positive effect on the concrete strength when done before final setting time of fresh concrete.

## 4. CONCLUSIONS

Effect of pulverised glass on the compressive strength of revibrated concrete has been investigated and the results have been presented, analysed and discussed. From the study, the following conclusion were reached:

- The pulverised glass is a good pozzolana and physical properties of both aggregates and that fresh concrete conformed to BS standards.
- The compressive strength of the cubes having 0% replacement with revibration was found to exceed those with non-revibration (0% PGP) by 11% increment and while optimum PGP percentage replacement was at 20%.
- Thus then paper recommends that PGP can be used as a pozzolana in concrete production to replace binder (ordinary Portland cement) up to 20% provided the concrete will be re-vibrated up to 60 minutes at 10 minutes interval successions.


## ACKNOWLEDGEMENTS

The authors would like to thank Management of Federal University of Technology Minna for the accessibility of Laboratory equipment in the Department of Civil Engineering. The authors are greatly grateful to the organizers of Global virtual conference in Civil Engineering (GVCCE) for the privilege to present this paper.

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