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# Effects of varying Recycled Glass and Groundnut Shell Ash on Strength and durability Properties of Self Consolidating High Performance Concretes (SCHPC)

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**Abstract -** *The use of recycled wastes and Pozzolanic materials in concrete productions as gained popularity in development of new construction and engineering materials in recent time [1].This study highlights the effects of incorporating waste glass(WG) and groundnut shell ash(GSA)on both fresh and hardened properties of self-consolidating high performance concrete in sulphate and chloride environment. A total of 180 concrete cubes of 100mm x 100mm x 100mm were produced with waste glass(WG) as aggregate and OPC/GSA as binder, with percentage substitutions varied between 0% - 40% for both materials in the concrete. The concrete were designed and examined for fresh properties and hardened specimens tested through crushing to obtain their compressive strengths at age 7,14,21, and 28 days after curing in water as control and two other different media ($CaCl_2$ and MgSO4 at 5%concentration). The concentration of media and substitutions level of GSA and recycled glass used for this work was in accordance with similar researches carried out by[2, 3,4 ,5,6]. The result of experimental work revealed improved rheological and mechanical properties of SCHPC compared with the control at the curing ages. Conclusively, GSA and recycled waste glass acted as suitable SCM and VMA respectively by modifying the pore structures of the SCHPC and ease of workability at fresh stage. Therefore, incorporating these items in SCHPC development would not only solve the environmental problems posed by production of convectional concrete but also reduce the cost of concrete production.*

***Key Words*: Groundnut shell Ash; Rheological and Mechanical properties; Self-consolidating high performance concrete (SCHPC); Recycled waste glass (WG); Sulphate and Chloride environment.**

## 1.0 INTRODUCTION

The utilization and demand for concrete in the day by day activities of construction industry globally, has led to high consumption of cement as major binder and other concrete components[7].Thus in reducing consumption and high dependency on concrete materials, utilization of industrial wastes like wastes glass as aggregate, and Pozzolanic materials such as sugarcane baggase ash, palm oil fuel ash (POFA), and rice husk ash (RHA), groundnut shell ash(GSA) as supplementary cementing materials in SCHPC is a new trend in research area of development of new construction and engineering materials over two decades [8]. SCHPC is a new type of concrete which is used presently in concrete and engineering works globally with advantages of ease of workability, self-compactibility, high strength and durability over standard concrete. Apart from CO2emissions in cement production, the excessive utilization of river sand as fine aggregate may lead to exploitation of natural resources, the effect of using recycled aggregates on the fresh and hardened properties of SCHPC need to be investigated. The use of GSA has benefits such as less cement use, reduction in concrete production costs, improvement of the durability properties of the concrete and recycles of waste glasses would also reduce environmental pollution.

Researchers have proven that concrete produced with recycled glass as aggregate are of better strength with thermal durability and minimal water absorption's [9].The use of recycled glass as aggregate and GSA as SCM in SCHPC can greatly enhance the workability, durability and aesthetic appeal of the concrete. Glass is a unique inert material that could be recycled several times without changing its chemical properties and GSA is a suitable supplementary cementitious material with both materials improves Rheological and Mechanical properties of the SCHPC. The major global environmental authorities concerned is to reduce, as far as possible, release of carbon dioxide (CO2) to atmosphere, the disposal of postconsumer wastes in landfill and diversion to economically viable wastes product streams[10],for this reasons, this work examined the strength and durability performance of SCHPC developed by incorporating recycled glass and GSA with precautionary measures in the design and production to prevent it vulnerability like convectional concrete of known deterioration inheritance. SCHPC in this work was developed by exploiting the benefits of industrial waste glasses and groundnut shells ash (GSA) as fine aggregate and supplementary cementing materials. In this study, Various percentages of GSA and waste glass were kept at (0%, 10%,20%, 30% , 40%) to produce SCHPC and characteristics performance were measured after curing in two chemical solutions ($CaSO_4$ and $MgSO_4$ ) of varying concentration of 5% each at 7,14,12, and 28 days hydration periods by conducting workability test on fresh concrete and Compressive tests on the hardened concretes.

The percentage concentration of chemicals used as curing media, the substitutions level of waste glass and that of GSA (SCM) used for this research was based on some similar researches carried out by [11, 3, 6].

## 2.0 Materials and Method

in this research work , materials used were, OPC/GSA as binder: Waste glass/river sand as fine aggregate: crushed stones of 12.5mm as coarse aggregate, a super plasticizers, $CaSO_4$, $MgSO_4$ and clean water. Groundnut shell ash used for this research was an amorphous class F ash as classified by[14] and was obtained through semi-open burning in a constructed brick oven for 24 hour and later placed in an electrical furnace at temperature of 600 °C$\pm$ 20°C for 3hours. Consequently, the physical (sieve analysis, moisture content, specific gravity) and chemical (SEM, XRF and XRD) analysis were carried out on both samples of waste glass and GSA at the Soil Mechanics Laboratory of the Department of Civil Engineering, Physic Electronics laboratory of Science laboratory Department, Federal Polytechnic, Ede Osun State and Department of Civil Engineering, University of Ibadan, Oyo state, respectively. The results of physical and chemical properties of all materials used are presented in tables 1and 2 and Figures 1.0 respectively. The Coarse aggregate used for this work was granite stone of high quality with 12.5mm maximum diameter. While the fine aggregate used was crushed waste glass/ river sharp sand with 4.75mm maximum diameter. All aggregates used were of control moisture contents to prevent increase in the water content in the concrete mix. Cement used as the main binder is of Dangote brand that conforms to type1 cement as specified by [13].

**Table 1.0**: Physical properties of materials used

| Property | CA | FA | WG | OPC | GSA | Conplast SP430MS |
|---|---|---|---|---|---|---|
| size (mm) | 12.5 | 4.5 | 4.5 | - | - | - |
| Water absorption (%) | 0.38 | 1.10 | 0.93 | - | - | - |
| Specific gravity | 2.66 | 2.15 | 2.32 | 3.08 | 1.89 | |
| Fineness modulus | 6.2 | 2.08 | 2.12 | | | |
| Colour | | | | Grey | Grey | Brown |
| Passed on a 45-µm (No. 325) sieve (%) | | | | 96 | 100 | - |
| Relative Density (at 20oC): | | | | | | 1.190 |
| pH (concentrate) | | | | | | 8.5 |

**Source: Laboratory Analysis and Company Manual, 2018**

**Table 2.0:** Chemical compositions of materials used for experimental work

| Oxide Composition | % Composition OPC | % Composition (GSA -2) | % Composition Natural Sand | % Composition Glass Sand |
|---|---|---|---|---|
| Ferrous oxide ($Fe_2O_3$) | 3.89 | 1.80 | 0.76 | 0.22 |
| Silica ($SiO_2$) | 20. 60 | 16.21 | 88.54 | 72.08 |
| Calcium Oxide (CaO) | 62.81 | 8.69 | 5.33 | 10.45 |
| Aluminum Oxide ($Al_2O_3$) | 4.98 | 5.93 | 1.21 | 2.19 |
| Magnesium Oxide (MgO) | 2.06 | 6.74 | 0.42 | 0.72 |
| Sodium Oxide ($Na_2O$) | 0.35 | 9.33 | 0.33 | 13.71 |
| Potassium Oxide ($K_2O$) | 0.40 | 15.73 | 0.31 | 0.16 |
| Sulphite ($SO_3$-) | 1.43 | 6.43 | ------ | --- |
| LOI | 2.80 | 2.82 | ------- | ----- |

**Source:** Tan et'al, 2014and Laboratory Analysis, 2018. (Loss on Ignition (LOI) using XRF method)

### 2.1 Mix Proportions

A designed mix to obtain the target strength of 50Mpa at 28days hydration was employed for the production of SCHPC cubes at water / cement ratio of 0.35. The target strength was opined based on similar research in development of high strength concrete with use of fly ash as SCM with 100Mpa at 28days [14].Fine aggregates contents were replaced at 0%, 10%,20%,30%,and 40%with waste glass(WG).[6]recommends between 10% to 70% replacement levels for suitable

SCHPC. An amorphous ash classified as GSA-2 and was used as a supplementary cementitious material at different percentages of 10%, 20%, 30% and 40% by mass of total binder as this falls within the criteria set by [15].The mix proportions and variables of all the mixes are presented in Table 3.0 and table 4.0 below. All the designed mixes had the same binder content of 480 kg/m$^3$, the coarse aggregate at 960 kg/m$^3$ and fine aggregate at 730 kg/m$^3$ for all the mixes. Super plasticizer (HRWR) was kept at 2% to total binder to achieve the required fresh properties of SCHPC. Two samples were designed and labeled as WGCA0- WGCA40 which contains both admixtures (GSA and Waste glass) at0%, 10%, 20%, 30% and 40% substitution levels and WGCB0- WGCB40 with 0%, 10%, 20%, 30% and 40% GSA replacements.

**Table 3.0:** design Mix of SCHPC

| Mix No.A | Cement (kg/m$^3$) | Water (kg/m$^3$) | W/C Ratio | GSA(kg/m$^3$) | GSA(%) | Fine Aggregate (kg/m$^3$) | Waste glass (%) | Coarse Aggregate (kg/m$^3$) | Conplast SP430MS (S.P) (% B) |
|---|---|---|---|---|---|---|---|---|---|
| WGCA0 | 480 | 168 | 0.35 | 0 | 0 | 730 | 0 | 960 | 2 |
| WGCA10 | 432 | 168 | 0.35 | 48 | 10 | 657 | 10 | 960 | 2 |
| WGCA20 | 384 | 168 | 0.35 | 96 | 20 | 584 | 20 | 960 | 2 |
| WGCA30 | 336 | 168 | 0.35 | 144 | 30 | 511 | 30 | 960 | 2 |
| WGCA40 | 288 | 168 | 0.35 | 192 | 40 | 438 | 40 | 960 | 2 |
| Mix No.B | | | | | | | | | |
| WGCB0 | 480 | 168 | 0.35 | 0 | 0 | 730 | - | 960 | 2 |
| WGCB10 | 432 | 168 | 0.35 | 48 | 10 | 657 | - | 960 | 2 |
| WGCB20 | 384 | 168 | 0.35 | 96 | 20 | 584 | - | 960 | 2 |
| WGCB30 | 336 | 168 | 0.35 | 144 | 30 | 511 | - | 960 | 2 |
| WGCB40 | 288 | 168 | 0.35 | 192 | 40 | 438 | - | 960 | 2 |

**Source:** laboratory analysis and product manual, 2018

**Table 4.0** Variables for concrete mixtures

| Variables | by weight |
|---|---|
| W/B ratios | 0.35. by weight |
| Binder content | 480 kg/m$^3$ |
| GSA and glass content | 10%, 20%, 30%, 40% of binder by weight |
| Total air content | 4% |
| HRWR dosage | 2% of binder by weight |
| Net mixing time | 7 to 13 minutes |
| Segregation ration | 18% maximum |

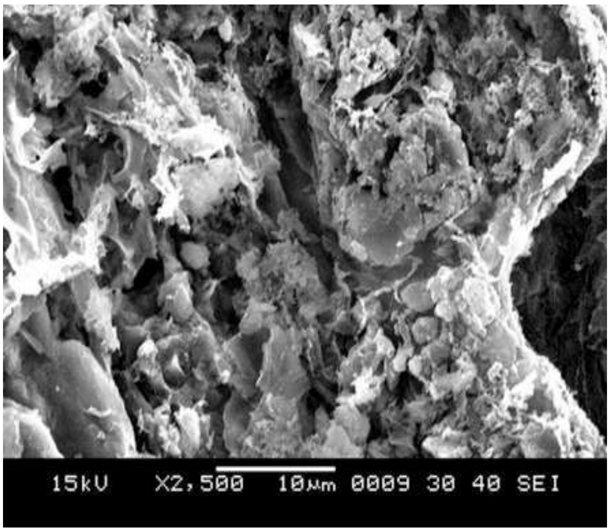



**Figure1.0:** SEM images (at 2500×) and physical appearance of GSA resembling Portland cement

The mineralogical and Morphological analysis of GSA were studied by using X-ray diffraction and SEM image as shown in figure 1.0 above. The SEM image revealed irregular surface with visible pores. The distinctly visible pores would enhance the pore structures formation of the concrete produced with this ash by improving the binding capacity of the component materials.

### 3.0 Results analysis and Discussions

3.1 workability of Fresh SCHPC

The influence of admixtures, relationship between segregation resistance of SCHPC and other fresh properties (flowing ability and filling ability) were investigated as they are interrelated with any change in one of these properties will influence the others[8, 17, 16]. The slump flow values was set between 600mm- 800mm to fulfill the requirement for fresh self-consolidating high performance concrete (SCHPC)as specified by [18,19]

**Figure 2.0:** Fresh properties determination at concrete laboratory

**Table 5.0:** Fresh properties of SCHPC

| Description | L-Box | V-Funnel Time(s) | Slump Flow (mm) | $T_{500mm}$ (Time) (s) | Segregation resistance Index |
|---|---|---|---|---|---|
| WGCA0(control) | 0.79 | 4.80 | 695 | 2.89 | 4.6 |
| WGCA010 | 0.83 | 6.10 | 720 | 2.72 | 5.30 |
| WGCA020 | 0.92 | 6.70 | 725 | 3.15 | 6.10 |
| WGCA030 | 0.94 | 6.90 | 738 | 3.92 | 6.50 |
| WGCA040 | 0.95 | 7.10 | 730 | 3.55 | 7.70 |
| | | | | | |
| WGCB0(control) | 0.83 | 5.70 | 730 | 3.10 | 5.90 |
| WGCB10 | 0.88 | 5.30 | 700 | 3.40 | 6.30 |
| WGCB20 | 0.93 | 5.20 | 690 | 3.65 | 6.50 |
| WGCB30 | 0.96 | 5.10 | 680 | 3 .82 | 6.80 |
| WGCB40 | 0.98 | 5.18 | 650 | 3.86 | 7.00 |

Source: laboratory analysis, 2018

### 3.2 Effects of waste glass and GSA on fresh properties of SCHPC

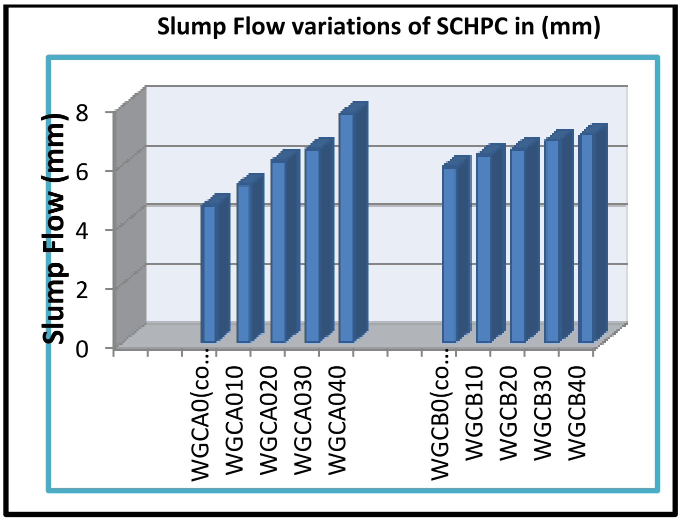
It was observed that for any increase in substitution levels of both samples, there is an increase in segregation values with reduction in slump flow values. This may be attributed to the higher volume of GSA substituted by mass, the Blaine specific surface area of GSA which was given as 21.89 $m^2/g$, the viscosity property of the waste glass and its grading significantly affects the flowability of SCHPC

#### 3.2.1 **Flowability**

The effect of replacement of GSA and waste glassat different concentrations levels reflects on Time of flow and slump flow values variations for both specimens as the amount of GSA and waste glass increases, the slump flow values decreases with slump flow value of control (WGCB0) with highest at 730mm and WGCB40 with the lowest at 650mm for GSA, while waste glass contained SCHPC control (WGCA0) was having lowest value of 695mm .However, all values are within the specified values as contained in[15,18].The values obtained are closely related with one observed by [20,8,21].

#### 3.2.2 **Segregation resistance**

Segregation resistance is an important factor in design of SCHPC. The stability of the concrete was examined with the use of screen stability test method as specified by[18] and visual observation during the slump flow and L-box tests with no bleeding observation. The results obtained revealed good segregation resistance as specified by [15].The values for WGCA0, WGCA10, WGCA20, WGCA30 and WGCA40 were 5.9%, 6.3%, 6.5%, 6.8%, and 7.0% and WGCB0, WGCB10, WGCB20, WGCB30 and WGCB40 were 4.6%, 5.3%, 6.1%, 6.5%, and 7.7% respectively for the two design samples. The use of GSA and waste glass as SCM and VMA improves the segregation property of the two samples during and after the process of transport and placing [20].



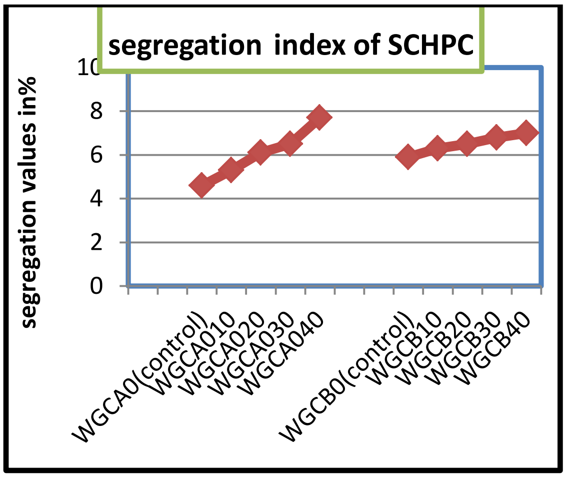




**Figure 3.0:** Slump flow variations and segregation resistance index of two Specimens (WGCA & WGCB)

### 3.3 Effects of waste glass and GSA on hardened properties of SCHPC

#### 3.3.1 Compressive strength

Previous researches have proved that admixtures enhance the strength and durability properties of SCHPC at later stages[17,22]. Incorporating GSA and waste glass in this research with necessary precautions has proved the importance of these admixtures in both cases. The compressive strength of the mixes increases as curing age increased up to 20% replacement in all conditions and this is in accordance with [23]. Generally, strength development of the mixes increased and target strength obtained at 20% substitution level compared with control. These results are similar with those obtained by [24,25,17], with use of fly ash, RHA and POFA within the values specified by[26]for high strength concrete.

#### 3.3.2. Water Absorption of Mortar

Water absorption was examined by using a mortar prism size of 40 mm × 40 mm × 160 mm. The samples were dried after 28 days hydration period to obtain constant weights and were immersed in water to determine the rate of their water absorptions. The process of obtaining the values was in accordance with(ASTM C-642 (2006) and the processes reported by [20, 27].The SCHPC containing waste glass(WG) has higher resistivity to water penetration and this may be due to inherited properties of type of industrial waste glass used as fine aggregate. The water absorption rate of the two classes of sample was calculated as:

$$\text{Water absorption}(\%) = \frac{m_2 - m_1}{m_1} X100$$

Where
$m_1$is the mass of oven dried specimen in air and
$m_2$ is mass of the surface dried specimen after immersion

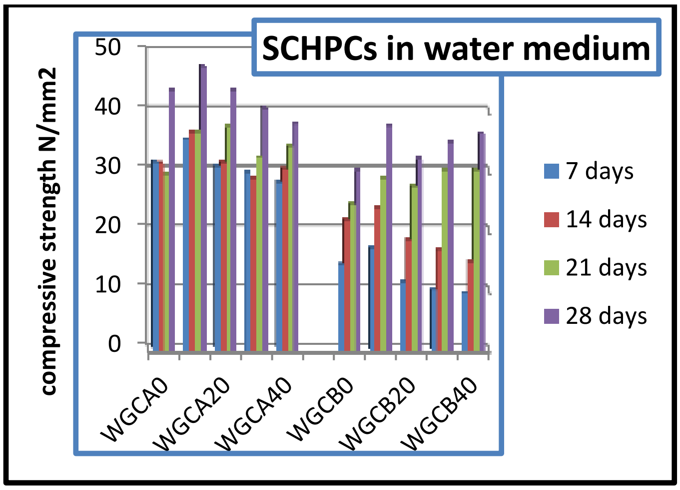
#### 3.3.3 Chloride penetrations

100 mm × 100 mm × 30 mm square slabs were used in carrying out the test. A dam of 15 mm height and 15 mm width was cast as an integral part of the slabs around its perimeter to form a basin for the chloride solution. The slabs were moist cured for 14 days, then dried in laboratory environment for another 14 days. After the drying period, a 5% $CaCl_2$ solution prepared with distilled water was used on the top surface for 28 days. Samples were analyzed using procedures for the determination of chloride in soil samples, and the results were recorded in mg/kg.

### 6.0 Hardened properties (Compressive Strength Result)

**TABLE 6.0:** Compressive Strength of Glass Crete/ GSA specimens of SCHPC in water medium

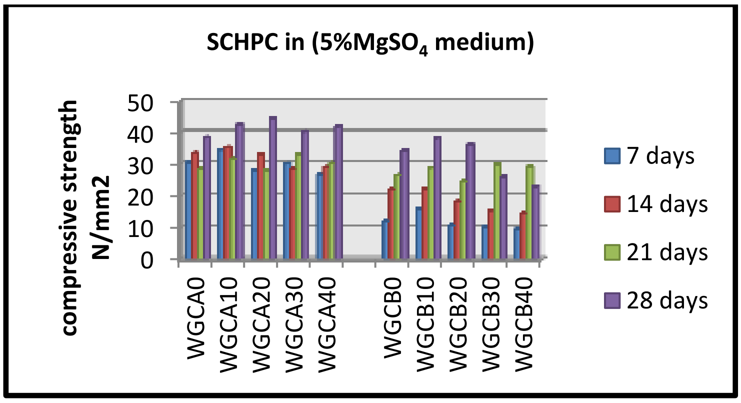
| SAMPLES | Water | | | |
|---|---|---|---|---|
| | 7 days | 14 days | 21 days | 28 days |
| WGCA0 | 27.00 | 28.70 | 35.20 | 39.80 |
| WGCA10 | 31.74 | 30.46 | 38.66 | 59.57 |
| WGCA20 | 30.70 | 34.57 | 35.50 | 51.60 |
| WGCA30 | 26.43 | 29.20 | 35.30 | 46.90 |
| WGCA40 | 26.47 | 29.86 | 31.60 | 43.40 |
| | | | | |
| WGCB0 | 14.44 | 28.4 | 31.20 | 42.11 |
| WGCB10 | 18.52 | 34.2 | 36.69 | 49.00 |
| WGCB20 | 13.69 | 16.6 | 32.70 | 40.33 |
| WGCB30 | 10.47 | 14.8 | 28.30 | 36.21 |
| WGCB40 | 9.8 | 14.0 | 26.60 | 33.01 |




The above graph and table, revealed the compactibility of GSA and WG in specimens labeled "WGCA" with early strength development of average value of 28N/mm² at 7days hydration period compare with other specimens (WGCB) with average strength of 13N/mm².The values obtained in "WGCA" specimens, is within values specified by ASTM C 39 (AASHTO T 22) for high strength concrete. The early strength wide gap between the two samples was as a result of viscosity modification roles played by addition of waste glass and indication of GSA belonging to class F ash with slow early strength development compare with class C ash [28].However, the interactions between all admixtures(GSA/SP/WG), has improves rate of strength developments of both samples of SCHPCs proportionally as hydration periods increases with high strengths values of 38.80 N/mm² (control),59.57 N/mm²,51.60 N/mm²,46.90 N/mm²,43.40 N/mm²and 42.11N/mm² (control), 49.00N/mm² ,40.33N/mm², 36.21N/mm², 33.01N/mm²respectively for both classes of samples. It can be seen from results analysis that the target strength value of 50 N/mm² was achieved at up to 20% replacement(51.60 N/mm²) in a specimens containing waste glass(WG) and GSA and 10% substitution level (49.00N/mm²)for specimen without WG.

**TABLE 7.0:** Compressive Strength of Glass Crete / GSA specimens of SCHPC in (5%$MgSO_4$)

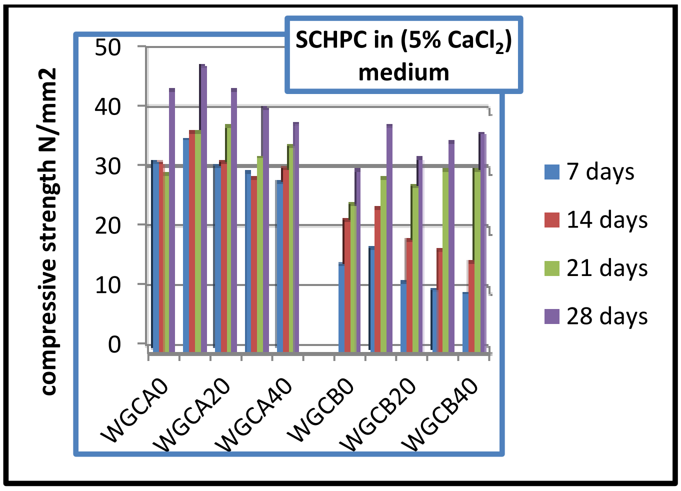
| SAMPLES | Magnesium Sulphate ($MgSO_4$) (5%) | | | |
|---|---|---|---|---|
| | 7 days | 14 days | 21 days | 28 days |
| WGCA0 | 30.38 | 33.39 | 28.42 | 38.43 |
| WGCA10 | 34.56 | 35.26 | 31.65 | 42.60 |
| WGCA20 | 28.00 | 33.20 | 28.00 | 44.50 |
| WGCA30 | 30.17 | 28.44 | 33.10 | 40.30 |
| WGCA40 | 26.63 | 28.96 | 30.23 | 42.10 |
| | | | | |
| WGCB0 | 12.23 | 22.33 | 26.40 | 34.33 |
| WGCB10 | 16.00 | 22.34 | 28.85 | 38.34 |
| WGCB20 | 10.83 | 18.25 | 24.70 | 36.25 |
| WGCB30 | 10.08 | 15.48 | 30.00 | 25.98 |
| WGCB40 | 9.6 | 14.45 | 29.25 | 23.10 |



The durability analysis of the two specimens' revealed little impacts of 5% $MgSO_4$ in strength reduction of SCHPC samples at every substitution levels. This may be due to non-penetration of the salt during the hydration period, mineralogical and Morphological formation of groundnut shell ash used for the experiment. The sulphate resistivity of SCHPC samples is closely related to (ASTM C 1012) guideline.

**TABLE 8.0:** Compressive Strength of Glass Crete specimens of SCHPC in (5% $CaCl_2$)

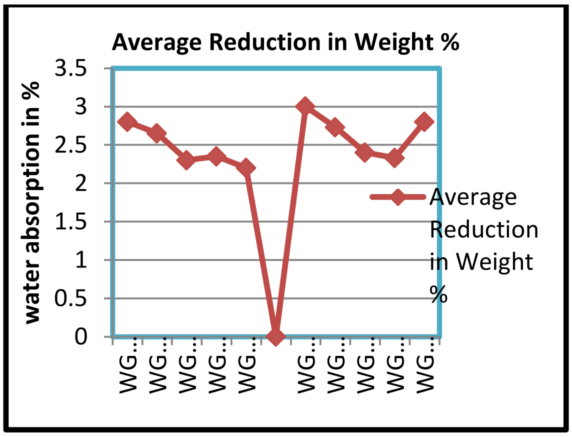
| SAMPLES | Calcium Chloride $CaCl_2$ (5%) | | | |
|---|---|---|---|---|
| | 7 days | 14 days | 21 days | 28 days |
| WGCA0 | 31.56 | 31.30 | 29.40 | 43.54 |
| WGCA10 | 35.30 | 36.40 | 36.57 | 47.66 |
| WGCA20 | 30.70 | 31.50 | 37.39 | 43.60 |
| WGCA30 | 29.80 | 28.70 | 32.28 | 40.50 |
| WGCA40 | 28.13 | 30.30 | 34.20 | 37.96 |
| | | | | |
| WGCB0 | 14.21 | 21.66 | 24.40 | 30.00 |
| WGCB10 | 17.10 | 23.66 | 28.67 | 37.61 |
| WGCB20 | 11.23 | 18.30 | 27.50 | 32.00 |
| WGCB30 | 10.12 | 16.80 | 30.10 | 34.80 |
| WGCB40 | 9.46 | 14.75 | 30.20 | 36.30 |




The results obtained indicate strength reductions in both samples. This may be due to the Alkaline Silica Reaction between glasses; cement/GSA and calcium Chloride ($CaCl_2$).it can be deduced that 30% replacement is suitable for $CaCl_2$ environment in SCHPC containing waste glass as fine aggregate while10% replacement level may be suitable for SCHPC without waste glass. However, both samples of SCHPC had their strength values below the target strength of 50Mpa at 28days hydration periods, but suitable for construction in this environment.

**Table 9.0:** Water absorption rate at 28 days hydration period

| Mix Design | Average Reduction in Weight % |
|---|---|
| WGCA0 | 2.80 |
| WGCA10 | 2.65 |
| WGCA20 | 2.30 |
| WGCA30 | 2.35 |
| WGCA40 | 2.20 |
| | |
| WGCB0 | 3.00 |
| WGCB10 | 2.73 |
| WGCB20 | 2.40 |
| WGCB30 | 2.33 |
| WGCB40 | 2.80 |




The graph and table above shows the level of water penetration in percentage of various concrete mix of SCHPC at hydration periods of 28days. Water absorption is one of the durability properties and (EFNARC 2005) guideline specifies the value between 3-6% for high strength concrete. It is obvious that the admixtures (GSA/WG) plays important roles in rheological and mechanical properties of all classes of samples with control in each case with highest water absorption values of 2.8% and 3.0% respectively. The results indicate reduction in water absorption rates as the percentage of GSA/WG increases. This means the admixtures are good filler to the pores of SCHPC and this allows the specimens to gain early strength as observed during compressive strength tests. The results are in similar pattern with one observed by[25,20] with use of fly ash and silica fume as Mineral admixtures.

**4.0. Conclusions**

The research work has revealed the importance of admixtures on the properties of SCHPC as both fresh and hardened properties greatly depend on characteristics of cement, cementitious material and aggregates.

The slump values, flow patterns and rate of water and chloride penetration is an evidence that the waste glass and groundnut shell ash at appropriate substation levels strongly improves the characteristics strength of the developed SCHPC compares with ordinary concrete. With little impact of sulphate and chloride in SCHPC developed strength reduction, SCHPC developed can be applied in sulphate and chloride environment.

The characteristics strength values of the developed SCHPC at up to 40% replacement level performed better and is suitable for production of SCHPC in an environment where high strength, durability and ease of work are required.

**5. Acknowledgement**

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**CONFLICT of Interest**

**On behalf of all authors, the corresponding author states that there is no conflict of interest.**

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