SUITABILITY OF WASTE GLASS POWDER AS PARTIAL REPLACEMENT OF CEMENT IN SANDCRETE BLOCK

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ABSTRACT

Waste materials, glass inclusive abound everywhere in the environment which has negative impacts on the environment. Also, the need for more and alternative building materials opens opportunities for sourcing of suitable materials. This paper investigates the suitability of Waste Glass Powder (WGP) as a cementing material to partially replace conventional Ordinary Portland Cement (OPC) in sandcrete block. To determine that, the particle size effect was evaluated using glass powder of sizes less than 100µm. A series of tests were conducted to determine the chemical composition of the WGP for cementitious characteristics and to study the effect of 10%, 20%, 30% and 40% replacement of OPC by WGP at mix proportion of 1:6 by weight. For the purpose of compressive strength test, 45 each of 225 x 225 x 450mm hollow sandcrete block and 100 x 100 x 100mm mortar cubes were produced and tested. The results show that the compressive strength of the blocks increases with increase in the percentage replacement. Blocks produced with 10% partial replacement have strengths which vary from 2.52N/mm^2 at 7 days curing to 3.42N/mm^2 at 28 days curing, while that of 20% partial replacement have strengths which vary from 2.84N/mm2 at 7 days curing to 3.46N/mm^2 at 28 days curing. The control blocks (at 0% of WGP) vary from 2.29N/mm^2 at 7 days curing to 3.29N/mm^2 at 28 days curing. It is thus observed that the 28 days curing compressive strength value of 3.46N/mm^2 at 20% replacement satisfies BS 2028 requirement. Thus, 20% is the optimum percentage replacement of OPC with WGP. It was also observed that blocks made with 10% replacement absorb less water than the control blocks. The implication of the results is that WGP is suitable for sandcrete blocks at 20% partial replacement and for water absorption property, up to 10% replacement is suitable.

Keywords: Suitability, sandcrete Block, Waste Glass Powder, Partial Replacement, Compressive Strength

INTRODUCTION

Waste materials, glass inclusive abound everywhere in the environment which has negative impacts on the environment. The need for more and alternative building materials opens opportunities for sourcing of suitable materials. Sandcrete block is a component of building which could catch on the opportunity from alternative materials for its production. Seeley (1993) defines sandcrete blocks as walling materials that are made of coarse natural sand or crushed rock dust mixed with cement in certain proportions and water, and moderately compacted into shapes. Also, sandcrete blocks are composite materials made up of cement, sand and water, molded into different sizes (Barry, 1969). Sometimes other ingredients such as pozzolanas may be added to reduce the amount of Portland cement in the mix. On molding they set, harden and attain adequate strength to be used as walling materials. Sandcrete is similar but weaker than mortar, for which the ratio is usually less or equal to 1:5. Sandcrete blocks may be either light weight or dense.

Glass is a transparent material produced by melting a mixture of silica, soda ash, and $CaCO_3$ at high temperature, followed by cooling to solidification without crystallization. The use of recycled glass saves lot of energy and the increasing awareness of glass recycling speeds up focus on the use of waste glass with different forms in various fields. Waste glass, which is one of the issues of environmental problems, is obtained from a variety of applications such as construction, automobiles, nose-diving submarines, doors and windows, utensils, waste containers, windscreen, medicinal bottles, soft-drink bottles, tube lights, bulbs, electronic equipment, etc. Glass waste is considered as non-decaying material that pollutes the surrounding environment. Meena and Karnik (2012) have shown that waste glass powder, if ground finer than 100μm shows a pozzolanic behaviour. It reacts with lime at early stage of hydration forming extra Calcium Silicate

Hydrate (C-S-H) gel thereby forming denser cement matrix. The use of waste glass as a component in concrete makes it a sustainable alternative to its use as land fill, therefore making it economically viable. If glass could be incorporated in cement products, it would greatly reduce the disposal of recycled glass and/or its use in lower valued markets such as fill and road base material.

The major cost component of sandcrete blocks is cement, since sand is readily available at relatively cheap prices. Any reduction in the cement content would have a noticeable reduction in the cost of this building material. Part of the solution to the high cost of cement could be in the form of materials that can replace cement either partially or wholly, yet achieving the desired properties. The use of waste glass powder as a partial replacement of cement in concrete has shown encouraging results in this regard (Topcu and Canbaz, 2004). Nigeria as a developing country is faced with many problems among which is inadequate housing for both rural and urban dwellers. The common building owned by an average Nigerian usually has its external and internal walls built with hollow sandcrete blocks according (Duna and Matawal, 2007). Cement, the binder being the most expensive input into the production of sandcrete blocks is probably the reason why commercial sandcrete block producers produce blocks with low cement content that will be affordable to Nigerians. Therefore the use of supplementary cementitious materials (SCMs) to offset a portion of the cement powder in sandcrete block will not only bring about lower cost with desired properties, but also a promising method for reducing the environmental impact of the cement industry. The most influential environmental concerns are in the production of greenhouse gas during the manufacturing of cement powder, and the consumption of non-renewable resources as raw materials.

MATERIALS AND METHOD

Materials

The materials used in this experimental investigation are ordinary Portland cement, waste glass powder, sand and water. Ordinary Portland Cement was used because it has important property that when mixed with water, a chemical reaction (hydration) takes place, which with time produces a very hard and strong binding paste for aggregate particles (Neville, 1981). Cement is a binder, a substance that sets and hardens, and can bind other materials together.

Waste Glass Powder was used in this research as a partial replacement of cement to determine its suitability in the production of sandcrete blocks. Meena and Karnik (2012) have shown that waste glass powder, if ground finer than 100μm shows a pozzolanic behaviour. The reduction of waste glass particle size was accomplished by crushing and grinding the waste glass in a mill. The waste glass used for this research was collected from shops and industrial waste dumps. Sand, a granular material composed of finely divided rock and minerals particles and the most common fine aggregates with particles size range from 0.0625mm to 2mm in diameter was used. It has a particle sizes that can assist in producing good workability and uniformity when mixed with cement in mortar and concrete mixture. The type of sand used in this research was coarse river washed sharp sand.

Water, required in sandcrete block mortar mix is used to hydrate cement and sand mixture to produce the required workability, and causes the mix to set and harden. The water used for all the experiment was clean, drinkable and free from impurities such as silts, clays, acid, alkaline salt and organic matter. The waste glasses used for this research were collected, crushed and ground to powder, for chemical analysis, sieve analysis and other tests.

Methods

The methodology adopted in this research is laboratory experimental method. The preliminary laboratory tests carried out on samples to ensure conformity to standards are:

1. Sieve Analysis Test
2. Specific Gravity Test
3. Bulk Density Test
4. The Consistency of a Standard OPC Paste
5. Initial and Final Setting Times of OPC Paste

Other laboratory tests to achieve the objectives of this investigation include:

1. Chemical Analysis of Waste Glass Powder
2. Compressive Strength Test
3. Water absorption Test

Production of Sandcrete Blocks

Forty-five (45) of 225 x 225 x 450mm hollow sandcrete blocks were produced with the OPC partially replaced at varying percentage of 10%, 20%, 30% and 40%. The control sample was the zero percent (0%) replacement. The mix ratio used was 1:6 (cement: sand) because it requires higher percentage replacement of cement than 1:8 mix ratio. The cement and sand were batched by weight. The cement and waste glass powder were thoroughly mixed, before mixing with the sand. Although mechanical mixer could be used, hand mixing was employed because most of the block industries use manual mixing for small scale work. Water was measured and added in just sufficient quantity and turned over severally to secure adhesion; the mix was then poured into the machine mould, compacted smoothed off with a steel face tool. After removal from the mould, the blocks produced were left on pallets under cover for at least 24 hours to allow for proper hydration and setting. The compressive strength test was carried out at ages 7, 14, and 28 days curing. Water absorption tests were carried out after the 28 days curing.

Cubes Production

Forty five (45) of 100x100x100mm cubes were also cast to measure the compressive strength after 7, 14 and 28days. The batching and mixing of constituents was the same as described in the production of sandcrete blocks. The cubes were produced at the same varying percentage replacement of the OPC with WGP in the range of 10 – 40% at 10% interval. The cubes were crushed using the compressive testing machine each at 7, 14 and 28 days curing after casting.

Compressive Strength (Destructive) Test

The compressive strength of blocks samples was determined by crushing in universal compression testing machine in accordance to BS 2028, 1364 (1968). The weights of the block and cubes samples were taken before the compressive test was conducted. The samples of blocks were crushed each at 7, 14 and 28 days curing. The crushing load was recorded and the compressive strength was obtained from the following equation:

$$U_{cs} = \frac{P}{(BL - 2ab)}$$

Where U_{cs} is the crushing strength (or compressive) of block in N/mm^2

P = the failure load

B = Overall breadth of the sandcrete block

L = Overall length of the sandcrete block

a = Length of the hollow in bed face

b = breath of the hollow in bed face

The compressive strength of cubes were also determined by crushing them in the compression testing in accordance with Bureau of Indian Standards, IS 10086 (1982). The crushing load was recorded and the compressive strength was obtained from the following equation:

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

Where f_c = compressive strength in N/mm^2
P = crushing load in Newton
A = cross-sectional area of the specimen in mm^2

Water Absorption (Non-destructive) Test

Each sample of the blocks, whose weights had been taken in the dry state and noted, was fully immersed in water. The time taken for full immersion was noted, and period of twenty-four (24) hours was allowed to elapse. After the 24hours, the wet block samples were removed and weighed. The difference between the dry and wet weights of each block was then calculated by subtracting the dry weight from the wet weight. From this the water absorption capacity of the block was determined from the following expression:

$$\text{Water absorption capacity} = \frac{\text{Wet Weight } (W_w) - \text{Dry Weight } (W_d) \times 100\%}{\text{Volume of Block}}$$

RESULTS AND DISCUSSIONS

Chemical Composition

The result of the chemical analysis of the waste glass powder is presented in Table 1. The percentage combination of silicon dioxide, SiO_2 (65.8%), aluminium oxide, Al_2O_3 (1.98%) and iron oxide, Fe_2O_3 (1.20%) present in the powder is 68.98%. This is higher than the 40.46% reported by Dashan and Kamang (1999) and a little less than the 70% minimum requirement for pozzolanas as specified by ASTM C618-78, 1978. The slight difference in the percentage composition might have resulted from the mineralogy of the waste glass powder. The loss on ignition, 0.4% is less than the 12% maximum requirement for pozzolanas. This suggests that waste glass powder contains low carbon which can reduce the pozzolanic activity of the powder.

Compressive Strength (Destructive) Test

Table 2 shows the summary of variation of compressive strength with increase in WGP content and curing periods. The table reveals that the compressive strength increases with age of curing and also increases with increase in WGP content up to 20% replacement after which it starts decreasing. The decrease in strength may be due to the fact that, the partial replacement of cement with WGP beyond 20% caused a reduction in the quantity of cement available in the mix for hydration process, thereby reducing the stable strength formation of cementitious compounds. At twenty-eight (28) days hydration period, the blocks made with 100% OPC have 3.29N/mm^2 compressive strength; 90% OPC have 3.42N/mm^2 compressive strength and 80% OPC have 3.46N/mm^2 compressive strength which meet the minimum required standard of 2.5 N/mm^2 for sandcrete blocks as specified by Nigerian Industrial Standard, NIS 87 (2000). The 20%WGP replacement satisfies the British Standard requirement of 3.50N/mm^2, therefore 20% replacement is the optimum replacement level of OPC with WGP. This may be due to the silica content at this level which is within the required amount. From the results in tables 3, 4 and 5, it can be seen that the density of OPC/WGP hollow sandcrete blocks falls within the range specified for sandcrete blocks (500-2100 Kg/m^3). This implies that the WGP content does not significantly affect the density of hollow blocks.

The standard deviation measures the variability of the strength. The values of standard deviation for 7, 14 and 28 days compressive strength results as shown in Tables 4, 6, and 8 obtained from values of compressive strengths in Tables 3, 5 and 7 are 0.69N/mm^2, 0.75 N/mm^2 and 0.81 N/mm^2 respectively. This indicates an increase in the deviation with curing age. The maximum compressive strength obtained was 3.46N/mm^2 at 28 days test at 20% replacement of cement with waste glass powder and the minimum compressive strength obtained was 1.00N/mm^2 at 7days test at 40% replacement. However the mean compressive strength from the entire block samples for 7, 14 and 28 days curing are 2.016N/mm^2, 2.562N/mm^2 and 2.748N/mm^2 respectively. These values also show an increasing trend with the curing age. The 14 and 28 days mean compressive strengths are within the range of the values recommended by Nigerian Industrial Standard, NIS 87 (2000). Nigerian Industrial Standard, NIS 87 (2000) recommends that the lowest crushing strength of individual load bearing blocks shall not be less than 2.5N/mm^2 for machine compacted and 2.0N/mm^2 for hand compacted sandcrete blocks. However, BS 2028 (1968) recommends 3.45N/mm^2 for the mean strength and 2.59N/mm^2 for the lowest individual strength of sandcrete block. The 28 days mean strength value of 2.748N/mm^2 does not conform to the BS 2028 (1968) specification but it is greater than the National Building Code specification of 2.00N/mm^2 minimum strength requirements for sandcrete blocks.

The results of compressive strength tests of the cubes are as shown in Table 9. The compressive strength of the cubes increased from 10% to 20% cement replacement with waste glass powder, and afterward decreased drastically as the percentage replacement increases to 30% and 40%. This is suggestive of increased strength-forming hydration activity per unit weight of the waste glass powder in comparison with cement up to 20% replacement. Increase compressive strength up to 20% cement replacement with WGP in relation to the control may not be unconnected with the fineness of the waste glass powder. Although the compressive strength reduces after 20% cement replacement with WGP, this is likely due to the fineness factor in strength determination which no longer has influence beyond 20% cement replacement with WGP.

Water Absorption Result

The result of water absorption test of the blocks is shown in Table 10. The result reveals that the blocks containing waste glass powder (WGP) at 10% replacement absorb less water than the control blocks (block with 0% cement replacement with WGP). The closest in value to that of the control is the block made with 20% replacement. From this result it can be concluded that blocks with WGP up to 20% absorb more fluid as such fail faster.

From the preliminary result of tests carried out on the materials, the following findings were made;

1 Sieve analysis result reveals that 17.9% of the sand passes through 0.006mm BS sieve size. The grading of the sand thus falls within the zone1 limit of (15-34% passing 600μm size) specified by BS 882 (1973).
2 The specific gravity of fine aggregate used was 2.62. This falls within the limit of (2.6 - 2.7) specified for natural aggregates by Neville (1981).
3 The bulk density of un-compacted and compacted sand was found to be 1546.61 Kg/m^3 and 1605.94 Kg/m^3 respectively. This gives the ratio of un-compacted to compacted bulk density of 0.96, which falls within the range of 0.87-0.97 specified for normal light weight aggregate by BS 882 (1973).

4 The consistency and setting time of cement revealed an initial setting time of two hours forty minutes (2hrs 40mins) and a final setting time of three hours three minutes (3hrs 3mins) which falls within the limit of forty five minutes (45 mins) initial setting time and ten hours (10hrs) final setting time specified by BS 12 (1978) for ordinary Portland cement.

5 The sieve analysis of WGP showed that 95.39% pass through the 150μm sieve and 22.70% pass through the 75μm sieve size; the powder used therefore has a fineness modulus level similar to that of the cement it replaced.

6 The specific gravity of WGP was found to be 2.39. This value is within the 1.9-2.4 range specified for pulverized fuel ash (PFA) by Neville (1981).

7 The value of the bulk density of WGP is 1.37 $g/cm^3$and that of OPC 1.21g/cm^3, which are above the minimum value of 1.14g/ cm^3 reported by Rajmane (2003).

8 The results for both initial and final setting times indicate increase with increase in WGP content, with values for 10%, 20%, and 30% replacement found to be within the recommended range for OPC paste (not less than 45 minutes for initial and not greater than 10hrs for final setting time). However, that of 40% replacement was not less than the recommended 45 minutes initial setting time, but the final setting time was more than the recommended 10hrs limit.

From the summary of results presented above, it can be concluded as follows:

i. The chemical composition of WGP for cementitious characteristics shows the presence of four major oxides of Portland cement (SiO_2, Al_2O_3, Fe_2O_3 and CaO). The percentage combination of this major compound present is approximately 70% which satisfy the minimum requirement for pozzolanas as specified by ASTM C618-78 (1978). Therefore, the waste glass powder shows a cementitious characteristic.

ii. The optimum percentage replacement of OPC with WGP in the sandcrete blocks was found to be 20% from the compressive strength tests results. The compressive test results show a steady decrease in strength of all samples containing 30 – 40% replacement.

iii. Water absorption results at 28 days curing reveal that the blocks containing waste glass powder (WGP) at 10% replacement absorbed less water than the control blocks (blocks with 0% cement replacement. The closest value to the control is at 20% replacement. From these results it can be concluded that blocks with WGP at 10% absorb less fluid than the control blocks.

iv. The compressive strength results for partial replacements from 10 – 40% at interval of 10% at 7, 14 and 28 days curing show considerable increase in strength with the age of sandcrete block made with WGP inclusion. The optimum strength of OPC + WGP blocks was found to be 3.46N/mm^2 at 20% replacement. This result falls within the mean value of 3.5 N/mm^2 prescribed by BS 2028 (1968) and is greater than the maximum average value of 2.5N/mm^2 prescribed in Nigerian Industrial Standard, NIS 87 (2000). Sandcrete blocks can therefore be produced using waste glass powder as partial replacement for cement up to 20%, and for the water absorption property replacement up to 10% is satisfactory.

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TABLES OF RESULTS

Table 1: Chemical composition of waste glass powder

Constituent	Composition (%)
Fe_2O_3	1.20
CaO	10.84
SiO_2	65.80
MgO	-
Al_2O_3	1.98
Na_2O	17.89
K_2O	1.88
L. O. I	0.40

Table 2: Compressive strength of blocks

% Replacement	Compressive strength (N/mm^2)		
	7 days	14 days	28 days
OPC:WGP, 100:0	2.29	3.04	3.29
OPC:WGP, 90:10	2.52	3.18	3.42
OPC:WGP, 80:20	2.84	3.22	3.46
OPC:WGP, 70:30	1.43	2.04	2.07
OPC:WGP, 60:40	1.00	1.03	1.50
Mean Compressive strength $\ddot{X} = \sum X/N$	2.016	2.562	2.748
Variance $\sigma^2 = \sum(X - \ddot{X})^2/N$	*0.477*	*0.566*	*0.654*
Standard deviation $\sigma = \sqrt{\sigma^2}$	*0.69*	*0.75*	*0.81*

Table 3: Density and compressive strength of blocks at 7 days curing

% WGP	Average weight of block (Kg)	Average density of block (Kg/m^3)	Average failure load (kN)	Compressive streng (N/mm^2)
0	24.00	2131.14	115	2.29
10	23.89	2121.67	126	2.52
20	23.25	2164.83	141	2.84
30	23.00	2042.62	72	1.43
40	22.80	2037.40	33	1.00

Table 4: Standard deviation at 7 days compressive strength of samples

Block sample	Compressive strength, X(N/mm^2)	$(X - \ddot{X})$	$(X - \ddot{X})^2$
1	2.29	0.274	0.075
2	2.52	0.504	0.254
3	2.84	0.824	0.679
4	1.45	-0.586	0.343
5	1.00	-1.016	1.032
	$\sum X = 10.08$		$\sum(X - \ddot{X})^2 = 2.383$

Total number of samples N = 5

Mean Compressive strength $\ddot{X} = \sum X/N = 10.08/5 = 2.016 N/mm^2$
Variance $\sigma^2 = \sum(X - \ddot{X})^2/N = 2.383/5 = 0.477$
Standard deviation, $\sigma = \sqrt{\sigma^2} = \sqrt{0.477} = 0.69 N/mm^2$

Table 5: Density and Compressive Strength of Blocks at 14 days curing

% WGP	Average weight of block (Kg)	Average density of block (Kg/m^3)	Average failure load (kN)	Compressive strenç (N/mm^2)
0	22.45	1993.78	152	3.04
10	22.15	1967.14	159	3.18
20	22.10	1962.70	161	3.22
30	22.40	1987.34	102	2.04
40	22.30	1956.90	67	1.33

Table 6: Standard deviation at 14 days compressive strength of samples

Block sample	Compressive strength, X(N/mm^2)	$(X - \ddot{X})$	$(X - \ddot{X})^2$
1	3.04	0.478	0.228
2	3.18	0.618	0.382
3	3.22	0.658	0.433
4	2.04	-0.522	0.272
5	1.33	-1.232	1.518
	$\sum X = 12.81$		$\sum(X - \ddot{X})^2 = 2.833$

Total number of samples N = 5
Mean Compressive strength $\ddot{X} = \sum X/N = 12.81/5 = 2.562 N/mm^2$
Variance $\sigma^2 = \sum(X - \ddot{X})^2/N = 2.833/5 = 0.566$
Standard deviation, $\sigma = \sqrt{\sigma^2} = \sqrt{0.566} = 0.75 N/mm^2$

Table 7: Density and compressive strength of blocks at 28 days curing

% WGP	Average weight of block (Kg)	Average density of block (Kg/m^3)	Average failure load (kN)	Compressive strenç (N/mm^2)
0	24.55	2180.28	164	3.29
10	23.60	2095.91	171	3.42
20	22.80	2024.87	173	3.46
30	22.00	1953.82	138	2.07
40	23.00	2042.62	72	1.50

Table 8: Standard deviation at 28 days compressive strength of samples

Block sample	Compressive strength, X(N/mm^2)	$(X - \ddot{X})$	$(X - \ddot{X})^2$
1	3.29	0.542	0.294
2	3.42	0.672	0.452
3	3.46	0.712	0.507
4	2.07	-0.678	0.460
5	1.50	-1.248	1.558

$\sum X = 13.74$	$\sum(X - \ddot{X})^2 = 3.271$

Total number of samples N = 5

Mean Compressive strength $\ddot{X} = \sum X/N = 13.74/5 = 2.748 N/mm^2$

Variance $\sigma^2 = \sum(X - \ddot{X})^2/N = 3.271/5 = 0.654$

Standard deviation, $\sigma = \sqrt{\sigma^2} = \sqrt{0.654} = 0.81 N/mm^2$

Table 9: Average compressive strength development of cube samples

% WGP	7-day average compressive strength (N/mm^2)	14-day average compressive strength (N/mm^2)	28-day average compressive strength (N/mm^2)
0	2.83	3.88	3.98
10	3.02	3.42	4.02
20	3.11	3.91	4.11
30	2.26	2.26	3.26
40	1.00	1.80	1.08

Table 10: Water absorption test

% WGP	Weight of block before immersion in water, M1 (kg)	Weight of block after immersion in water for 24 hrs, M2 (kg)	% Water absorbed
0	24.80	26.70	7.66
10	21.40	23.70	10.75
20	23.55	25.60	8.70
30	23.05	24.95	8.24
40	22.95	24.02	4.66

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