Investigation into the Suitability of Powdery Glass as a Partial Replacement for Cement in Concrete

Adeniran Jolaade Adeniran, Joseph Olaoye & Abdulwaheed Olorukooba
Department of Civil Engineering, Federal Polytechnic, Ilaro, Ogun state, Nigeria
Dapo.olaoye@federalpolyilaro.edu.ng; adeniran.adeala@federalpolyilaro.edu.ng

Abstract

Abstraction of materials for cement production largely results in environmental degradation hence the search for substitute is necessary. Broken glass often litter construction site as environmental nuisance and health hazards. This waste utilized, was crushed and finely ground by mechanical grinding machine. The powder generated was passed through 75µm sieve size which falls within range of particle size of cement (50µm-90µm). Particle size distribution was carried out on both fine and coarse aggregate in accordance with (BS 1377-2:1990); Workability test was also carried out on concrete. Specific gravity was carried out on cement and fine aggregate. Concrete cubes were cast replacing cement from 0% to 20% adopting a water cement ratio (W/C) of 0.5 and cured for 7, 14 and 28days respectively. Water absorption and consistency test were carried out on conventional and modified concrete. The result showed that particle size distributions of the aggregates are well graded. All the samples tested have true slumps. Cement, fine aggregate and powdered glass specific gravities are 2.63, 2.65and 2.83 respectively. The result showed that 10% replacement has higher water absorption rate of 1.11% while 5% replacement has lower water absorption rate of 0.54%. The result further showed that control (0%) has compressive strength of 25MPa while at 5%, 10%,15% and 20% cement replacement compressive strength are 27.33MPa,25.58MPa, 22.18MPa and 18.26MPa respectively at 28days.The study concluded that the modified concrete at 28days, with 0.5 W/C ratio at 5% and 10% cement replacement exhibits the similar properties of normal weight concrete.

Keywords: *Waste glass, Cement, Workability, Compressive Strength, Water absorption*

Introduction

Concrete is a durable and mouldable construction material that consists of cement, coarse aggregate, fine aggregate and water but sometimes admixtures are combined, depending upon its use and requirement. Concrete production uses large quantities of natural resources such as aggregates and cement (binder). Cement contributes to the release of carbon dioxide during its production. About one ton of carbon dioxide is released into the atmosphere for the production of one ton of cement; cement production therefore generates approximately 7% of the world's total yearly production of CO_2. Nigeria cement production is reported to hit 60 million tonnes per annum by year hence increase in environmental pollution and its attendant human health hazards. Green house gas like CO_2 leads to global warming and it contributes to about 65% of global warming. To reduce this environmental impact, alternative binders are introduced to make concrete. Cement is a common construction material and its production causes the same environmental concerns as that of regular concrete.

posited that recently there has been an increasing incentive to minimize the environmental effect of the construction industry through programs such as the Leadership in Energy and Environmental Design (LEED). Green Building Rating System, which rewards for sustainable construction practices (CaGBC, 2009). Greater sustainability of the construction industry can be achieved if a portion of the virgin aggregate or cement is replaced with waste materials. Significant experimental work was performed on the use of pozzolanic materials to be used as partial replacement of cement in concrete, such as fly ash, silica fume and ground granulated blast furnace slag. Due to the successful implementation of these waste materials into regular concrete there is increased desire to find new post-consumer materials which can be used as a partial replacement for cement. The experimental work presented in this research looks at the use of powdery glass, as an eco-friendly material to replace cement in the production of concrete. Raghavendra&Virendra(2015) investigated the compressive strength, split tensile strength and water absorption of M40 grade of concrete blends in with 20% replacement of waste glass powder in cement and partial replacement of waste foundry sand in fine aggregate. From the results, it was observed that compressive strength was less on 7 and 14 days yet it increases on the 28th day. High strength values were found at 40% replacement level in strength

parameters. The compressive strength and split tensile strength of concrete at 7, 14 and 28 days' increases initially as the level of replacement of waste glass powder and waste foundry sand increased. Jitendra &Saoji (2014) studied the replacement of glass powder differing in part from 0 to 40%, at increase of 10% and tested for its workability, compressive strength, split tensile strength, alkalinity test, density measurement, water absorption test, volume of permeability test and ultrasonic pulse velocity test for the age of 7, 28 and 56 days and the results were contrasted with those of conventional concrete. The overall test outcome indicated that Waste Glass Powder could be used in concrete as a decent substitute of cement. It was likewise discovered that workability of concrete decreases as level of glass powder increases. Slump value of investigation's concrete extended from 60 to 80 mm, highest compressive strength was seen when Glass Liquid Powder (GLP) replacement is about 20%. Most elevated split was seen when GLP substitution is about 20%. Vandhiyan R. et al, (2013) also carried out experimental study on the replacement of cement by glass powder and the outcome appeared there was increase in the early strength at 7 days especially at 15% where glass powder invigorated a 29% expansion while that of control mix of cement mortar decreased to 23% at 28 day. Vasudeuan Gunalaon and Parveenberwal, (2016) investigated on the compressive strength of concrete with partial replacement of cement by glass powder at 7, 14 and 28 days of samples, the results showed that 20% glass powder substitute produced compressive strength of concrete more than that of control mix at 28th day for the grade of 30. Ana and Joana, 2012 , derived the effect of waste glass on properties of concrete. In that research crushed waste glass powder (WGP) was used in mortar as a partial cement replacement (0%, 10% and 20%) material to ascertain applicability in concrete. Spiesz, Rouvas & Brouwers (2016) investigated the fresh and compacted concrete characteristics. The concrete mixes were made with up to 60 % volume of fine and coarse waste glass aggregates. The results showed that the concrete satisfy mechanical characteristics coupled with high durability, and improved air distillation properties.

Materials and Methods

This work involved both field and laboratory work. The field work involved sourcing for aggregates (coarse and fine granite) and waste glass. The laboratory experiments were carried out in the Department of Civil Engineering Concrete Laboratory of the Federal Polytechnic Ilaro, Ogun State, Nigeria. Waste glasses were collected from building demolition sites and grounded to a powdery form at Abeokuta, Ogun State, Nigeria. The powdery glass passed through 75microns and X-ray fluorescent was carried out on the powdery glass in accordance to ASTM C617, 2008.





Figure 1: Glass before grinding Figure 2: Glass powder after grinding

Ordinary Portland Cement (OPC) of Dangote 3X brand was purchased from a retailer at Ilaro, Ogun State, Nigeria with properties conforming to (BS12. (1996) and BS 12. (2000)). The fine and coarse aggregates were obtained from constructions site in Ilaro, and the aggregates were passed through nest of sieves arranged from the largest size (19mm) atop to the dust tray below. Portable water was used for both mixing and curing. The concrete mix design of 1:2:4 and water-cement ratio of 0.5 for control and other mixes were adopted. The fresh concrete was cast in mould (150mmx150mmx150mm) for purpose of testing and curing. The cubes were cured and compressive strength tests were carried out on the cured cubes at 7, 14 and 28 days. Also 28 days water absorption tests were carried on concrete cube in accordance with BS 1881(1986). Cubes were tested for engineering properties in accordance with British standard. Batch weights of materials are shown in Table 1 below.

Table 1: Batch weight of materials in (kg) with 0.5 water-cement ratio

Materials	0%	5%	10%	15%	20%
Cement	11	10.45	9.90	9.35	8.80
F.A	22	22	22	22	22
C.A	44	44	44	44	44
W.G.P	0	0.55	1.10	1.65	2.20
Water	5.5	5.5	5.5	5.5	5.5

Results and Discussions

The result of XRF of powdery glass is presented in table below

Table 2 : XRF analysis of chemical composition of oxides in Ground Waste Glass (GWG).

Oxides	Chemical composition of oxides (%)
SiO_2	64.12
Al_2O_3	3.65
Fe_2O_3	0.40
TiO_2	0.15
CaO	10.08
P_2O_5	0.99
K_2O	0.65
MnO	0.25
MgO	2.22
Na_2O	13.48
LOI	0.23
Total	100.00

According to Table 2 above, the summation of the three main pozzolanic-indicating oxides (SiO_2, Al_2O_3, TiO_2) is 71.95% which makes it a Class F pozzolan (this class lies between 70% and above according to ASTM C617). So it indicates that WGP is a strong pozzolan thereby good for concrete production.

A. Particle Size distribution of aggregates

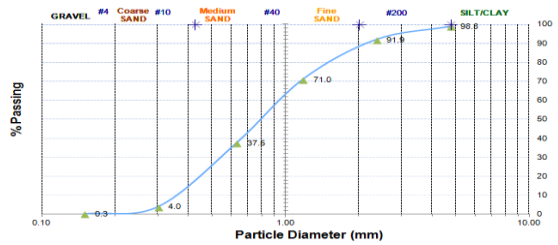


Figure 3: Particle Size distribution curve for fine aggregates.

It was observed that C_u and C_c were 2.64 and 0.82 respectively for fine aggregate. Since C_u lies between 1 and 3 while Cc lies between 0.5 and 2, the fine aggregate is well graded in agreement with BS1377. Finesse modulus of fine aggregates is 3.96 which fall between 3.6 and 6.9 which is good for concreting work.

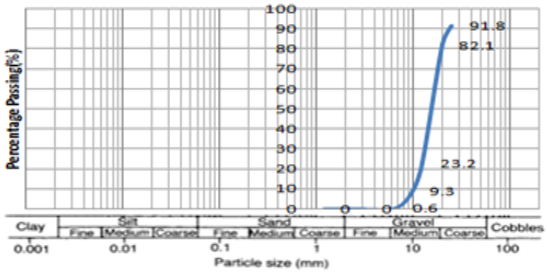


Figure 4: Particle Size distribution curve for coarse aggregates.

It was also observed that C_u and C_c is 1.06 for coarse aggregate. Since C_u lies between 1 and 3while C_u lies between 0.5 and 2, so the coarse aggregates is well graded in accordance with BS1377. Finess modulus of coarse aggregates is 3.90 and which fall between 3.6 and 6.9 and which is good for concreting work.

C. Specific gravity

Table 3: Results of specific gravity test on GWG, Fine aggregate and Cement.

Materials	Specific gravity
Cement	2.63
Glass powder	2.83
Fine aggregate	2.65

From table 3 above, specific gravity of the cement deployed in the experiment was 2.63 compare to 3.15 for conventional cement; specific gravity for both ground waste glass powder (GWG) and fine aggregates (FA) i.e sand are 2.83 and 2.65 respectively. Comparing specific gravity of GWG and Cement, it can be deduced that waste glass powder is denser than cement which means the weight density of concrete produced using GWG will be denser than concrete produced through cement alone.

C. Workability

This is the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished' (ACI, 1990).Workability test using slump method was carried out on fresh concrete in accordance with BS 1881 – 102; 1983 and the result is presented in figure 5 below:

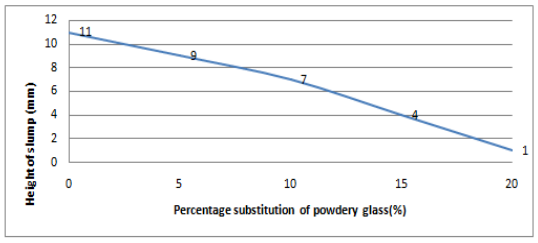


Figure 5: Slump height of modified concrete

From Fig.5, it was observed that conventional concrete slump height was 11mm, but reduced to 9mm at 5% replacement and dropped to 7mm at 10%, and later declined to 4mm at 15%,finally reduced to 1mm at 20% replacement in a linearly relationship. However, it was observed that the modified concrete is as suitable as the conventional concrete, as both concretes have true slumps. As the GWG increases, the slump height reduces at a fixed W/C ratio. This indicates that the amount of water in the concrete matrix decreases though the concrete can be easily be handled and placed. The reduction can be attributed to presence of large surface area in the finely-divided glass hence more voids in the GWG than normal cement.

D. Standard Consistency

Standard consistency test was carried out on cement mortar in accordance with (BS 12 .1978).The result obtained is as presented in table 4 below

Vicat apparatus	0 %	5 %	10%	15%	20%
Needle penetration(mm)	5	5	6	5	6
Needle with collar(mm)	6	5	5	7	6
Needle without collar(mm)	5	5	5	5	7

The results of the standard consistency test on ground waste glass (GWG) and cement are presented above in accordance to BS 12: 1978; which shows that the consistency tests are satisfactory because all values obtained fall between 5mm and 7mm required.

F. Setting time of cement paste.

This is a measure of initial and final setting time of cement paste and was carried out in accordance to (BS 12, 1978).The initial and final setting time of cement paste used in this research study is presented in table 5 below.

Table 6: Setting time of Cement Paste (initial and final setting time)

Sample	Initial setting time	Final setting time
Cement	1hour30mins	2hours45mins
5%	1hour45mins	3hours
10%	2hours	3hours 15mins
15%	2hours 10mins	3hours30mins
20%	2hours30mins	4hours

From table 6 above, it was observed that the initial setting time and final setting time of cement were 1 hour 30mins and 2 hours 45 mins respectively and 5% GWG, 10% GWG, 15% GWG and 20% GWG their initial and final setting times fall within 45mins and 10hours, which is satisfactory in accordance to British Standard 12 (1978, 1996, 2000) which states that the minimum initial setting time for cement paste is 45mins and maximum final setting time is 10 hours. The result indicates that increment in percentage replacement delay both the initial and final setting times.

G. Density

The weight of each concrete cubes were obtained prior to testing to ascertain the density. This was done in accordance to BS 1881-114.(1983).

Density = Mass/Volume.

The result was presented in table 7 below

Table 7: Density of GWG Concrete at 28days

W/C	**Waste Glass replacement %**	**Weight(g)**	**Density (g/m^3)**
0.5	0	8388.66	2486.00
	5	8244	2453.33
	10	8158	2417.38
	15	8440	2500.84
	20	8051	2406.99

Referring to table 7 above, the density of control specimen was 2486kg/m^3 and at 5% GWG replacement, it decreased to 2453.33kg/m^3 and later at 10% cement substitute with GWG it reduced to 2417 and getting to 15% the density increased to 2500 and which later dropped to 2406.99kg/m^3 at 20% replacement. It was observed that density lies

within the range of 2300 to 2500kg/m^3 which fall within the range of density of conventional concrete. In term of density, GWGC has similar characteristic as conventional concrete.

H. Water Absorption

The weight of the cubes were weigh after demoulding and also 28 days curing in water in order to ascertain water absorption and which was carried in accordance with BS 813-2. (1995).
Water absorption rate = (Final weight of cubes after curing - Initial weight of cubes before curing) / Initial weight of cubes before curing. The result is presented in table 8 below.

Table 8 : Water absorption (28 days)

w/c	Replacement	Weight before (g)	Weight after (g)	Water absorption (%)
0.5	0%	8287.17	8388.66	1.22
	5%	8199.67	8244	0.54
	10%	8068.33	8158	1.11
	15%	8353	8440.33	1.05
	20%	8051	8123.6	0.79

The concrete cubes at 28days curing were weighed after demoulding. It was observed that the 0% crushed ceramic tiles has water absorption of 1.22% and that 5% level of replacement the concrete cube has water absorption rate of 0.54% while 10% has 1.11%, 15% and 20% has water absorption of 1.05% and 0.79 % respectively. It was shown that increase in GWG led to decrease in water absorption of concrete as shown in Table 7. The water absorption for all concrete cubes were all good; according to Concrete Society, United Kingdom, concrete quality is classified as good if the saturated water absorption is between 0.89% and 3% though 5% and 20% were outside the range. In conclusion, the replacement levels from 5 to 20% of concrete with PG were all good.

I. Compressive Strength

The cubes were cured in water for 7days, 14 days and 28 days. The compressive strength was carried on 150mm x150mm cubes after days of curing in accordance with BS 1881- 116. (1983)

Compressive strength = Compressive Force/ Cross section Area (N/mm^2 or MPa)

Table 9: Compressive Strength Development.

DAYS	PERCENTAGE REPLACEMENT (%)				
	0	5	10	15	20
7	20.96	15.25	18.19	17.71	11.52
14	22.03	15.66	19.77	18.7	15.01
28	25	27.33	25.58	22.18	18.26

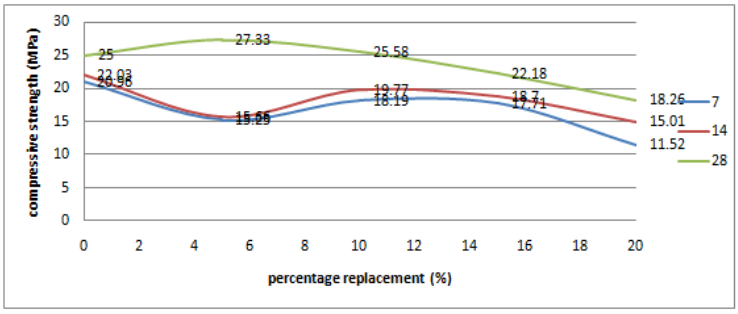


Fig.6: Curing days with compressive strength development.

The compressive strength at 28 days for convectional concrete is 25MPa. For the modified concrete, at 5% replacement, it increases to 27.33MPa. Proceeding to 10% it decreased to 25.58MPa, on getting to 15% substitute it decreased to 22.18MPa. At 20%, its compressive strength drastically reduced to 22.23MPa.It can be deduced from above explanation that the modified concrete attained optimum strength at 5% replacement which means to get maximum strength of 27.33Mpa, 10 % of GWG must be substituted for 10% cement in matrix of concrete.

J. Mathematical Model of Flexural Strength

The flexural strength is expressed as Modulus of Rupture (MR) in(N/mm^2) or (MPa) and is determined by standard test methods third-point loading(ASTM C 78) or centre-point loading (ASTM C 293).
Mathematical model was developed for flexural strength at 7, 14 and 28 days using the relationship between compressive strength (F_{ck}) and flexural strength (F_{st}) The result was presented in table 10 below with $F_{st} = 0.7\sqrt{F_{ck}}$.

Table 10: Mathematical model of flexural strength

PERCENTAGE REPLACEMENT (%)	NO. OF DAYS		
	7DAYS	14DAYS	28DAYS
0	3.20	3.29	3.50
5	2.73	2.77	3.66
10	2.99	3.11	3.51
15	2.95	3.03	3.30
20	2.38	2.71	3.00

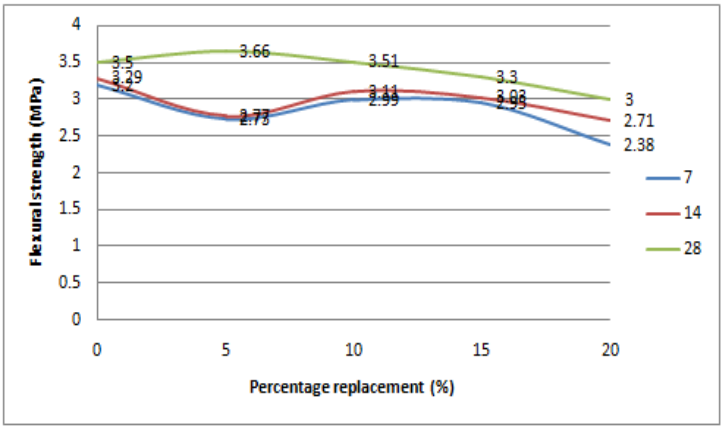


Fig.7: Flexural Strength against percentage replacement of GWGC

From figure 7 above, The flexural strength at 28 days for convectional concrete is 3.5MPa and at 5% replacement of GWG, it increased to 3.66MPa. At 10%, it decreased to 3.51MPa. At 15%, it decreased to 3.30MP and at 20%, it decreased to 3.0MPa. It can be deduced that the modified concrete attained optimum strength at 5% replacement of GWG with cement in concrete matrix.

K. Statistical Modelling of compressive strength at 28 days

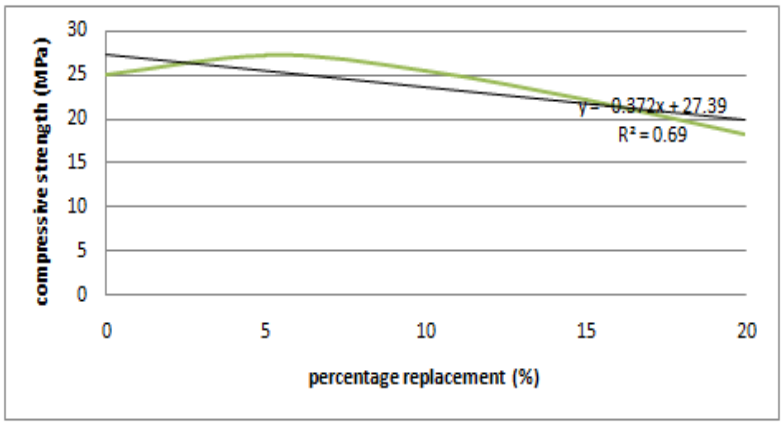


Fig. 8: Regression analysis showing relationship between compressive strength and percentage replacement of GWG.

Regression analysis showing relationship between compressive strength and percentage replacement of GWG in concrete matrix showed that there is fair correlation between compressive strength of modified concrete and replacement level of GWG in composition of concrete with $R^2 = 0.69$ with linear equation Fct = -0.3726x + 27.396.

With target strength of 25Mpa,

25 = -0.3726 + 27.3396

X = 6.3% of GWG can be used to substitute cement to produce concrete with compressive strength of 25MPa with 1:2:4.

IV. Conclusion

The experimental study showed that there is striking similarities with conventional concrete. The GWGC possess true slump, the densities of GWGC varies from 2300 to 2500 kg/m3 which has the same density similar to conventional concrete. Water absorption of modified concrete varies from 0.54 to 1.22 which classified as good. 5% substitute of GWG in concrete matrix produced highest strength of 27.33MPa.

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