Strength Characteristics of Concrete using Waste Glass Powder Strengthened by Renolith as Partial Replacement for Cement

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Abstract— **This study investigate the effects of using Environmental Waste Glass powder (EWG) to partially replace cement in concrete. Laboratory work was conducted on concrete cubes with cement content partially replaced at 0%, 10%, 15%, 25%, 50% and 75% by EWG powder strengthened by Renolith and tested for it workability and compressive strength. Results of workability tests indicate close agreement with normal concrete at 15-25% GP replacement. The compressive strength of normal concrete is 12.7% higher than 10%-15%GP. Addition of Renolith at 5-25% increases the strength characteristics of the concrete cube and at 50%-75%, the strength decreases. Maximum increase in strength of concrete occurred at 25% replacement with EWG powder and 25% Renolith. It is concluded that EWG powder improves the strength properties of concrete and provide sustainable alternative to the volume of land filling and reducing disposal problems.**

Keywords— **Concrete, Cement, Glass Powder, Renolith and Compressive Strength**

I. INTRODUCTION

Concrete is a civil engineering material resulting from the mixtures of cement, coarse and fine aggregates and water. Sometimes admixtures may be added to modify one or more properties in the fresh and/or hardened states of the concrete. The materials when properly batched and thoroughly mixed sets through the process of hydration and hardens into a concrete mass which is capable of resisting compressive stresses [1]. The use of wastes or by-products in concrete production has advantages for improving some or all of the concrete properties. Concrete is one of the most widely used construction materials in the world. However, the production of Portland cement, leads to the release of significant amount of CO_2, one ton of Portland cement clinker production is said to create approximately one ton of CO_2 and other greenhouse gases. Many researches are ongoing into the use of Ordinary Portland cement replacements, using many waste materials and industrial by products, for example, pulverized glass and ground granulated blast furnace slag etc. Glass powder is also used as a binder with partial replacement of cement which takes some part of reaction at the time of hydration; also it acts as a filler material. Glass produced in the World is discarded, stockpiled or land filled. This pattern has influenced environmental organizations to pressure the professional community to lower the amount of glass being discarded as well as find use to the non-recycled glass in new applications. The waste glass is one of the issues of environmental problem. Glass is used in a variety of applications right from construction, automobiles, nose-diving submarines, doors and windows, utensils, waste containers, windscreen, medicinal bottles, soft-drink bottles, tube lights, bulbs, electronic equipment, etc. Hence, the usage of glass has increased considerably, which has in essence, contributed to the increase of waste disposal.

II. RELATED WORK

Glass is amorphous material with high silica content, thus making it potentially pozzolanic when particle size is less than 75µm [2], [3]. Studies have shown that finely ground glass does not contribute to alkali – silica reaction. In the recent, various attempts and research have been made to use pulverized glass as a replacement in conventional ingredients in concrete production as a part of greenhouse management. The fact that glass has high silica content has led to laboratory studies on its feasibility as a raw material in cement manufacture. The use of finely divided glass powder as a cement replacement material has yielded positive results [4]. Optimal dosage range of this glass powder is chosen based on cement paste studies. Glass is an inert material which could be recycled and used many times without changing its chemical property [5]. Besides using waste glass as cullet in glass manufacturing, waste glass is crushed into specified sizes for use as aggregate in various applications such as water filtration, grit plastering, sand cover for sport turf and sand replacement in concrete [6].

Concrete is a mixture of cement, sand, coarse aggregate and water. The key factor that adds value to concrete is that it can be designed to withstand harshest environments significant role. In recent years, global warming and environmental devastation have become manifest harms, concern about environmental issues, and a changeover from the mass-waste, mass-consumption, and mass-production society of the past to a zero emanation society is now viewed as significant.

Normally glass does not harm the environment in any way because it does not give off pollutants, but if not dealt carefully, it can harm humans as well as animals, and it is less friendly to environment because it is non-biodegradable. Thus, the development of new technologies has been required.

III. MATERIALS

Materials used in this research includes; environmental waste glass material (EWGM), cement, fine aggregates, coarse aggregates, Renolith and water.

EWGM was collected locally from kano state, Nigeria and converted into powder form (Fig. 5) within Ado-Ekiti, Ekiti state. Glass is a rigid liquid i.e., super cooled liquid, static, not solid, not a gas but does not change molecularly between melting and solidification to a desired shape. Primarily glass is made up of sand, soda ash, limestone and other additives (Iron, Chromium, Alumina, Lead and Cobalt).

Cement used was ordinary Portland cement (OPC) of grade 42.5 (Dangote brand). It is the most common type of cement in Nigeria with general usage and obtained from Ado-Ekiti metropolis. Hence, it is the basic binder material for concrete.

Dry river sand and granite of average size 10mm to 20mm was used for casting all the specimen..

Renolith is a product of polymer admixture, yellowish-white (Fig. 1) designed to create a stable solid product when mix with Portland cement. This product was obtained from Ondo State, Nigeria.

Manufacturer claimed that its addition to concrete mix or soil will provide the following advantages:

a) A reduction of water/cement (w/c) ratio.
b) Improve workability through the plasticising effect of the polymer-dispersion.
c) Enhance good cohesion between the aggregates and the cement paste.
d) A reduction of micro-cracks.
e) Improve waterproofing and resistance to water permeation.
f) An increase in the elasticity/flexibility (flexural strength) without a decrease in compressive strength.
g) Long term stability.

In general, the product once mixed with the normal concrete will make the concrete to be super concrete (polymer concrete) which cannot be broken easily.

Afe Babalola University Potable water is generally considered satisfactory for mixing concrete. This water used for mixing and curing is clean and free from injurious materials like oils, acids, alkalis, salts, sugar and organic materials.

IV. METHODS

A) Pulverizing of Environmental Waste Glass Material (EWGM)

EWGM was pulverized locally with the pulverizer/grinding machine. Glass powder passing through sieve 600 μmm was considered for this research.

Fig. 1: Showing five litres sample of Renolith

Fig. 2: Pulverized Glass powder

B) Dilution of Renolith

Three different dilutions were selected to be used for this research. The Renolith is then diluted into 25%, 50% and 75% by weight. Table I shows the dilution obtained for this research.

Table I: Dilution of Renolith

Dilution percentage (%)	Renolith (g)	Water (g)	Total volume (g)
25	500	1500.00	2000.00
50	500	500.00	1000.00
75	500	166.67	666.67

C) Concrete Mix Proportion

Six different concrete mixes were chosen for this research using the mix ratio 1:2:4. Concrete with water cement ratio of 0.5 was adopted as normal concrete. In the other five mixes; 10%, 15%, 25%, 50% and 75% of cement was replaced by glass powder in weight. The mix proportions are shown in Table II.

Table II: Concrete Mix Proportions

Replace-ment (%GP)	Cement (g)	GP (g)	Fine (g)	Coarse (g)	Water (g)
0	1333	0	2667	5333	667
10	1200	133	2667	5333	667
15	1133	200	2667	5333	667
25	1000	333	2667	5333	667
50	667	667	2667	5333	667
75	333	1000	2667	5333	667

Following the mix ratios obtained from Table II above;

Concrete molds were cleaned and lubricated in preparation for the casting. Concrete components were mixed according to different percentages of cement replacement with EWGP. Water was added and the products mixed until the desired consistency was achieved.

The mold is then placed on a vibrating table to compact each layer as shown in Fig. 4. The concrete cubes are maintained at controlled temperature and humidity. This allows concrete to achieve optimal strength.

D) Slump Test

The concrete slump test is an empirical test that measures the workability of fresh concrete. Hence the workability of the various levels of cement replacement with glass powder (0%, 10%, 15%, 25%, 50% and 75%) for the concrete mix ratios of 1:2:4 was tested using slump test.

E) Compressive Test

The compressive strength is the maximum load per unit area acting on the concrete cubes at failure. The concrete cubes were removed from the curing tank 24 hours before loading. Excess water was wiped out using a clean towel. The weight of the specimen was recorded. The cube was tested at 7, 14, 21 and 28 days respectively using 2000 kN capacity compression testing machine as shown in Fig. 6. The maximum load at failure was recorded as shown in Table III.

(a) (b)

Fig. 3: Slump test preparation and measurement

Fig. 4: Vibrating concrete cubes table

Fig. 5: Concrete specimen in Curing Tank

Fig. 6: Crushing of concrete cube specimen

V. RESULTS AND DISCUSSION

Slump test Results

With reference to Table VI, the slump value of Normal concrete mixture gives a value of 42mm compare to concrete mix with glass powder of 10% is 35mm, 15% is 39mm, 25% is 44mm, 50% is 98mm and 75% are 107mm.Therefore, the value of Normal concrete mixture slump decrease at 10% and 15%, increase at 25%, 50% and 75% of waste glass powder (GP). Hence, slump values of 10 to 25% glass powder replacement indicate concrete can be used for foundations with light reinforcement and normal reinforced concrete placed with vibration. Slump values of 50% and 75% glass powder replacement indicate the concrete is having a high workability.

Compressive strength test

Fig. 7, shows that the compressive strength value of concrete at 10% glass powder replacement in the experiment is giving very high value of 12.24 N/mm^2 compare to Normal concrete mixture value of 10.15 N/mm^2. Also for the concrete mixture that contain 15%, 25%, 50% and 75% of glass powder mixture concrete gives a low compressive strength compare to Normal concrete. This increment of the positive value shows that with the mixture of glass powder into the concrete will achieve the early strength ratio's for the 14 days. Therefore, experiment using glass powder to replace with cement at 10% will give 14 days' strength compare to the Normal concrete.

Table III: Compressive strength with varying percentage of glass powder

Days	NC0	GP10	GP15	GP25	GP50	GP75
7	10.2	12.24	7.55	6.33	1.76	0.22
14	11.1	14.77	8.2	7.06	2.92	0.58
21	21.7	19.75	15.2	10.79	6.73	1.76
28	27.9	24.33	20.13	14.53	8.26	3.49

GP=glass Powder, NC=Normal Concrete

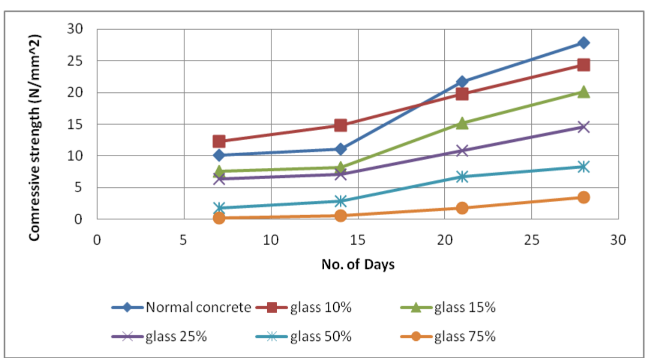

Fig. 7: Average of Compressive strength of concretes with varying amounts of glass powder at different days of curing

Table IV: Strength with varying percentage of Renolith (R25-R75)

Days	NC	G25 R25	G25 R50	G25 R75	G50 R50
7	10.2	9.1	4.5	6.4	7.4
14	11.1	17.1	7.0	6.7	12.8
21	21.7	26.1	7.8	7.1	14.5
28	27.9	31.9	8.0	8.9	16.8

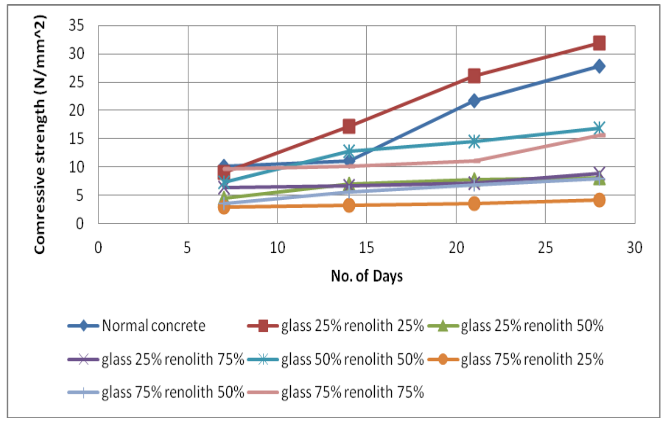

Fig. 8: Compressive strength of cubes with varying percentage of Glass powder and Renolith

Table V: Strength with varying percentage of Renolith (G75)

Days	NC0	G75R25	G75R50	G75R75
7	10.2	3.0	3.5	9.6
14	11.1	3.3	5.6	10.2
21	21.7	3.5	6.9	11.1
28	27.9	4.1	7.9	15.6

R=Renolith

Table VI: Slump test values with varying amount of glass powder

Replacement percentage (%)	Slump value (mm)
0 (Normal concrete)	42
10	35
15	39
25	44
50	98
75	107

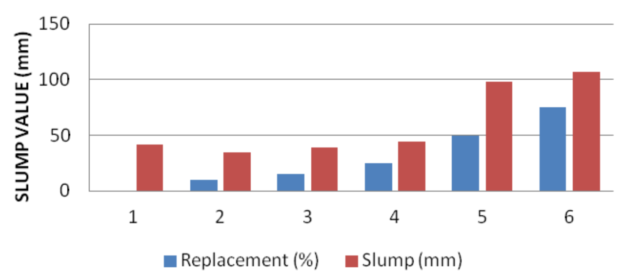

Fig. 9: Slump values of concretes with varying amounts of glass powder

At 21 and 28 days, it shows that average compressive strength of concrete with glass powder at 10 and 15% is giving positive value more than the target concrete value of dense concrete 24.0 N/mm^2, but still low compare to the Normal concrete mixture. At 25% and 50% is giving positive value within the target concrete value of light-weight concrete

7.0 to 18.0 N/mm^2 but, it's still low value compare to Normal concrete mixture. Therefore, compressive strength of concrete with glass powder at 10 to 50% shows a positive value of compressive strength at 28 days compare to mix ratio at 75% glass powder replacement of cement which is not achievable throughout the curing ages.

Referring to Fig. 8, the overall average compressive strength value of concrete at 7 days, 25% of glass powder and 25% renolith gave an average value of 9.09 N/mm^2 compare to normal concrete mixture of 10.15 N/mm^2 strength. Also for other concrete mixtures that contain glass powder and renolith mixture gives a low compressive strength compare to Normal concrete.

At 14 days the compressive strength of concrete with glass powder at 25% of glass powder and 25%renolith is giving very high value of 17.13 N/mm^2 compare to Normal concrete mixture value of 11.11 N/mm^2. Also for the concrete mixture that contain 50% of glass powder and 50%renolith gives a higher value of 12.82 N/mm^2 compare to Normal concrete mixture value of 11.11 N/mm^2. For other concrete mixture with glass powder and Renolith, gives a low compressive strength compare to Normal concrete. This increment of the positive value shows that with the mixture of glass powder into the concrete will achieve the early strength ratios for the 21 and 28 days at 25% of glass powder and 25%renolith.

At 21 and 28 days, it shows that average compressive strength of concrete with glass powder at 25% of glass powder and 25%renolith, is giving positive value more than the target concrete value of dense concrete 24.0 N/mm^2 and gives a high value of 31.91 N/mm^2 compare to normal concrete value of 27.87 N/mm^2. The compressive strength of concrete at 25% of glass powder and 50%renolith, 25% of glass powder and 75%renolith, 50% of glass powder and 50%renolith, 75% of glass powder and 50%renolith and 75% of glass powder and 75%renolith are giving positive value within the target concrete value of light-weight concrete 7.0 to 18.0 N/mm^2 of 8.03 N/mm^2 , 8.85N/mm^2, 16.84 N/mm^2, 7.92 N/mm^2, and 15.59 N/mm^2 respectively, but still low value compare to Normal concrete mixture of 27.87 N/mm^2 strength. Therefore compressive strength of concrete at 75% of glass powder and 25%renolith for concrete mix proportions at 28 days is not achievable throughout the curing ages.

Cost Analysis

The cost analysis as presented in Table VII to Table XI has shown that there is economic benefit in glass powder being used as partial replacement for cement in concrete. Unit rate calculation of 1 m^3 (1:2:4) for normal concrete (0% replacement).

Table VII: Cost analysis for Normal Concrete (NC0)

S/N	Description	Unit price (#)	Amount (#)
1	300kg of Cement	28	8,400.00
2	0.86 m^3 of Granite	7143	6,142.98
3	0.43 m^3 of Sand	2000	600.00
4	200 litres of Water	1.50	300.00
	TOTAL		#15,442.98

Table VIII: Cost analysis for GP10 Concrete

S/N	Description	Unit price (#)	Amount (#)
1	270kg of Cement	28	7,560.00
2	0.86m^3 of Granite	7143	6,142.98
3	0.43m^3 of Sand	2000	600.00
4	200litres of Water	1.50	300.00
	TOTAL		#14,602.98
	Percentage difference		5.44%

Table IX: Cost analysis for GP15 Concrete

S/N	Description	Unit price (#)	Amount (#)
1	255kg of Cement	28	7140.00
2	0.86m^3 of Granite	7143	6,142.98
3	0.43m^3 of Sand	2000	600.00
4	200litres of Water	1.50	300.00
	TOTAL		#14,182.98
	% difference		8.16%

Table X: Cost analysis for GP25Concrete

S/N	Description	Unit price (#)	Amount (#)
1	225kg of Cement	28	6,300.00
2	0.86 m^3 of Granite	7143	6,142.98
3	0.43 m^3 of Sand	2000	600.00
4	200 litres of Water	1.50	300.00
	TOTAL		#13,342.98
	% difference		13.60%

Table XI: Cost analysis for GP50 Concrete

S/N	Description	Unit price (#)	Amount (#)
1	150kg of Cement	28	4,200.00
2	0.86$m^3$of Granite	7143	6,142.98
3	0.43m^3 of Sand	2000	600.00

4	200 litres of Water	1.50	300.00
TOTAL			#11,242.98
% difference			27.20%

VI. CONCLUSION

The following conclusions were drawn from the properties of concrete made with partial replacement of cement with glass powder strengthened with Renolith;

a) Slump test for normal concrete was estimated to be 42mm and at 15-25% of glass powder (GP) replacement, the slump ranges between 39-44mm. This indicate true slump and it is recommended for foundation purpose.

b) Compressive strength of normal concrete (NC0) was slightly higher than that of 10-15% GP replacement. This result indicates that GP10-GP15 replacement can be suggested for similar application with normal concrete.

c) Strength characteristics of GP25-GP75 indicate lower strengths. The results are fair for GP25 and GP50 but very poor for GP75. This class may find suitable application in lower weight concrete structures.

d) Addition of Renolith between 5-25% at 28 days increases the strength of concrete and setting time but decreases with 50-75% replacement at GP25.

Using glass powder (GP) will not only provide economy, but help to reduce glass related environmental waste, provide concrete with strength comparable with normal concrete. Renolith on the other hand is expensive, hence it should be used for special purposes e.g., foundation (to stabilize the soil).

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