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Comparative Study on Compressive Strength of Coarse and Fine Glass-Aggregate Concrete

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ABSTRACT: *The improvement of concrete quality has been the priority of modern day construction industry while reducing the financial implications of the final product. This study focused on the use of glass as aggregate in concrete production. It presents a comparative analysis between glass usage as a coarse aggregate and as a fine aggregate. The fine and coarse aggregates used were partially replaced with fine glass and coarse glass respectively. The replacement was done at 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% by weight of aggregates. With other materias constant, using a design mix of 1:2:4 and water cement ratio of 0.6, the replacement was done and compressive strength and workability of concrete specimens determined. The concrete specimens were produced, cured and compressive strength determined at 7, 14, 21 and 28 days. The results showed that the glass-sand aggregate had a maximum compressive strength of 23.65N/mm^2 at 20% replacement level while glass-granite concrete had a maximum value of 20.65N/mm^2 at 10% replacement level. The workability of both concrete reduces as the percentage replacement increases. The compressive strength increment reduces as the concrete ages for both specimens but this reduction is more drastic for the glass-granite concrete. It was concluded that the glass-sand concrete be preferred, although from F-statistics, there is no significant difference between concrete produced from both methods at 5% level of significance.*

KEYWORDS: Glass, Aggregate, Compressive Strength, Workability

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I. INTRODUCTION

In the construction industry, glass have been employed sparingly in concrete production process. This may be attributed to the slippery nature of glass making it not to bond properly with other constitute elements of concrete [1]. Its application in the concrete process has basically been in powdered form used to partially replace the cement or binding element in the concrete matrix [2, 3, 4] due to the fact that it possesses pozzolanic properties.

Glass possesses other excellent properties like low permeability, high Young's Modulus, highly non-degradable, making it suitable for use as aggregate in concrete. Aggregates are responsible for the unit weight, modulus of elasticity and dimensional stability of concrete because these properties depend on the physical characteristics of the aggregate [5]. Different Researchers have tried to investigate the effect of glass aggregate on concrete strength and workability especially as fine aggregate component. [6]. Topcu and Canbaz [7] noted that the cost of concrete would be reduced if glass is employed as aggregate in the construction process. They explained that if crushed glass or cullet is properly sized and processed, they can exhibit characteristics similar to that of gravel or sand.

There have been very few researches on the use of glass as coarse aggregate [8]. This may be because of the fact that glass due to its smooth surface possess very weak cohesive property making it difficult to bond with other concrete elements. This study thus investigates the effect of coarse glass as coarse aggregate in comparison to fine glass as fine aggregate on concrete workability and compressive strength.

II. MATERIALS AND METHOD

2.1 Materials

The selected materials used in this study are locally available and are used in making concrete; they are;

i. Coarse aggregate (granite chippings) of maximum size 12.5mm
ii. Dangote brand cement (R 42.5, CB 4227)
iii. Fine river sand as the fine aggregate.
iv. Waste glass obtained from waste glass assemblage in a site in Port Harcourt.
v. Fresh water free of organic materials with pH value of 7.0.

The waste glasses were washed, cleaned and dried and then crushed into smaller pieces before they were subjected to sieve analysis to separate them into fine and coarse fractions.

2.2 Apparatus

The equipment used for this study were; 150mm x 150mm x 150mm steel moulds; slump cone (model HM-40, Gibson Company, USA) which meets the requirement of BS 1882-102 [9]; Compressive Strength Machine (Model 42070, Chandler Eng. USA) which meets the requirement of BS 1881-115 [10]; tag sieves, sensitive weighing balance, trowel, curing tank, steel rod and electric concrete mixer.

2.3 Methodology

2.3.1 Experimental Design

This study involved workability and compressive strength tests on concrete specimen using crushed glass to systematically replace coarse aggregate and fine aggregate. This partial replacement was done using 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% for both experiments. A constant mix proportion of 1:2:4 and water cement (w/c) ratio of 0.6 was employed for all concrete mixtures used in this research study.

2.3.2 Concrete Batching, Mixing and Curing

The concrete components (coarse aggregate, fine aggregate, and cement) were thoroughly mixed together in the electric concrete mixer using 1:2:4 design mix, after which water at 0.6 water-cement ratio was added. The aggregates were prepared in accordance with the requirements of BS 1017[11]. The concrete specimens produced from both methods were cured in a curing tank and subjected to two tests; workability and compressive strength at 7, 14, 21 and 28 days.

2.3.3 Workability Tests

The slump tests was employed as the measure of workability of the fresh concrete specimen. Two sets of workability tests (glass-granite concrete and glass-sand concrete) were performed for each percentage replacement. The slump mould was filled in three layers, with each layer compacted by a steel rod with 25 blows before pouring the next layer. The surface of the slump cone was levelled after filling the cone and allowed for about 2 minutes. The slump cone was then lifted off the concrete, thus allowing the pile of unsupported concrete to collapse. The difference between the initial and the final height of the concrete was measured and recorded as the slump.

2.3.4 Compressive Strength Test

The compressive strength of the concrete was determined using Equation (1)

$$f_c = \frac{P}{A} \qquad (1)$$

Where, P = Failure load in N

A = Cross – sectional area of test cube in mm^2

f_c = Compressive strength in N/mm^2

The load at which the concrete fails was recorded and the compressive strength calculated using equation (1).

III. Result And Discussions

3.1 Slump

The results of workability (slump) test for both experimental methods are as shown in Table 1

Table 1: Slump (mm) of glass-aggregate concrete

% wt of crushed glass	Glass-sand concrete			Glass-granite concrete		
	(1)	(2)	Mean	(1)	(2)	Mean
0	90.00	88.00	89.00	90.00	88.00	89.00
5	81.00	79.00	80.00	84.00	86.00	85.00
10	70.00	70.00	70.00	79.00	81.00	80.00
15	54.00	55.00	54.50	62.00	60.00	61.00

20	36.00	38.00	37.00	44.00	46.00	45.00
25	28.00	30.00	29.00	35.00	32.00	33.50
30	23.00	25.00	24.00	22.00	19.00	20.50
35	19.00	20.00	19.50	15.00	15.00	15.00
40	17.00	17.00	17.00	11.00	9.00	10.00

Result showed that the slump (workability) of concrete produced from both methods reduces as the percentage of glass increases as shown in Figure 1. The reduction in workability of the concrete produced from both methods may be attributed to the difference in density between the glass and the aggregates. The result also showed that the workability of the glass-granite concrete is greater than that of the glass-sand concrete for percentage replacement between 5% to 25% above which the reverse became the case. At 30% replacement of granite with glass, there is a sharp reduction in concrete workability whereas for the glass-sand case, the reduction in workability follows a steady pattern as the percentage replacement increases.

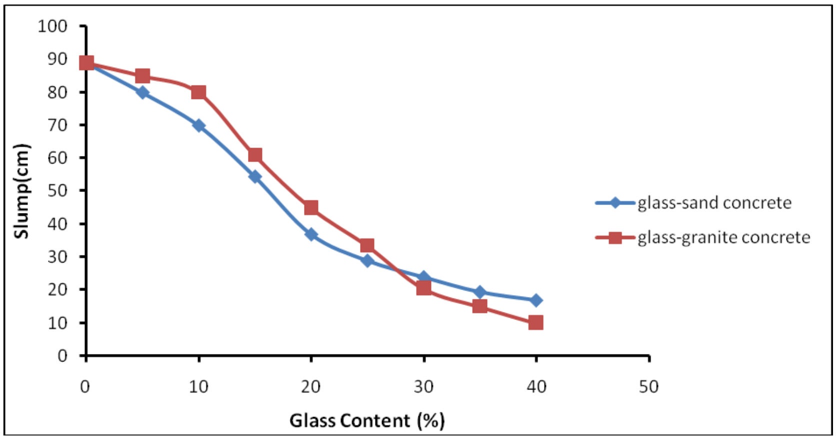

Figure 1: Slump (Workability of Glass Aggregate Concrete

3.2 Compressive Strength

The mean compressive strength test result for both methods of concrete production is presented as shown in Table 2.

Table 2: Mean Compressive Strength of Glass-Aggregate Concrete

% wt of crushed glass	Mean compressive strength (N/mm^2)							
	7 days		14 days		21 days		28 days	
	Glass -sand	Glass-granite	Glass-sand	Glass-granite	Glass-sand	Glass-granite	Glass-sand	Glass-granite
0	10.45	10.45	12.55	12.55	15.75	15.75	19.35	19.35
5	10.65	11.10	12.60	13.15	15.90	16.85	19.40	19.85
10	10.75	12.45	12.85	14.60	16.05	18.05	19.65	20.65
15	13.45	8.75	15.35	11.55	16.85	15.25	20.05	19.01
20	15.05	8.55	17.05	10.70	19.55	14.80	23.65	18.85
25	11.55	8.25	13.40	10.35	20.30	14.00	21.45	18.50
30	11.05	8.01	13.00	10.05	17.05	13.65	20.75	17.55
35	12.15	7.95	12.50	10.02	16.15	12.95	19.50	16.00
40	10.05	7.85	11.80	9.90	15.05	12.45	15.10	13.20

The effect of the use of coarse glass as coarse aggregates in comparison with the use of fine glass as fine aggregate in concrete is shown in Figures 2a to 2d. The result shows that the optimum replacement of granite chippings with glass as fine aggregate component is 20% while as coarse aggregate component is 10%. As fine aggregate component, 20% optimum replacement resulted in a compressive strength of 23.65N/mm^2 at 28 days, whereas as coarse aggregate component, the 28 days strength was found to be 20.65N/mm^2 at 10% optimum replacement.

For percentage replacements of 5% - 10%, glass as coarse aggregate produced slightly higher strength concrete compared to its fine aggregate counterpart. Result also showed that glass can be used as replacement for sand up to about 35% replacement level. Glass-sand aggregate produced concrete of slightly higher strength than the control concrete (0% glass) but as coarse aggregate, the replacement should not be encouraged beyond the 10% replacement level, as concrete of lower strength than the control were produced. Comparing the strength of concrete at both optimum levels, glass as fine aggregate produced much higher compressive strength concrete of 23.65N/mm^2 compared to 20.65N/mm^2 recorded by glass as coarse aggregate.

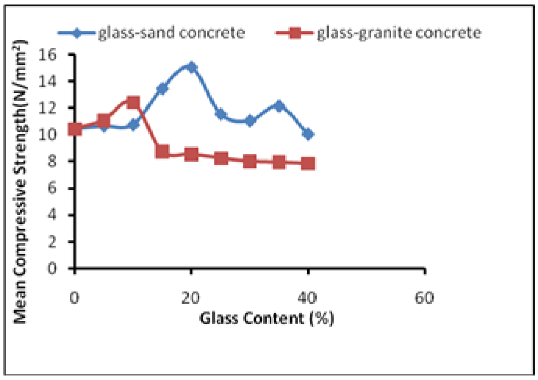

Figure 2a: 7 Days Compressive Strength of Glass Aggregate

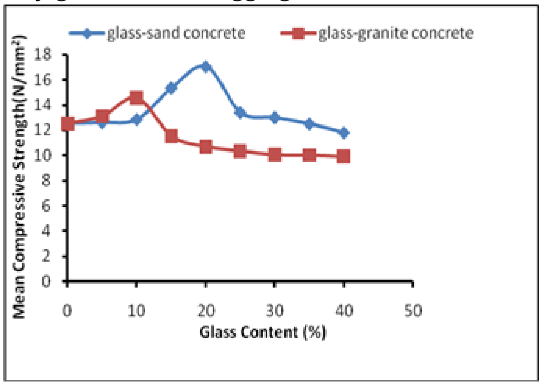

Figure 2b: 14 Days Compressive Strength of Glass Aggregate

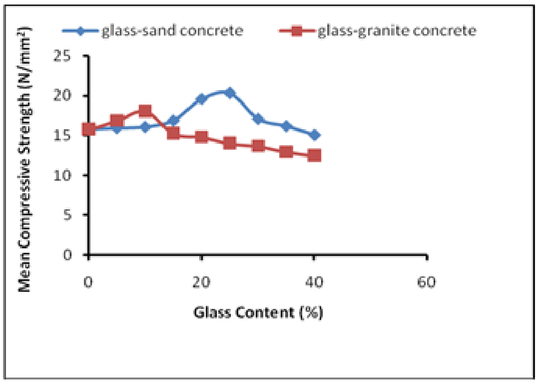

Figure 2c: 21 Days Compressive Strength of Glass Aggregate

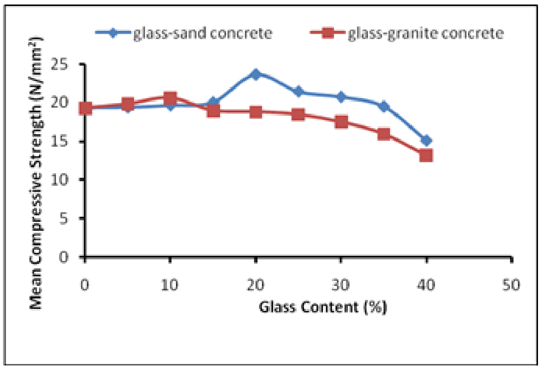

Figure 2d: 28 Days Compressive Strength of Glass Aggregate

3.3 Effect of Ageing

The ageing effect of glass aggregate concrete is discussed here with reference to the optimum replacement obtained for both methods of concrete production using the percentage increment in concrete strength, that is, 20% replacement for glass-sand aggregate concrete and 10% replacement for glass-granite aggregate. Table 3 presents the percentage increment in strength at the optimum levels for both concrete productions.

Table 3: Percentage Increment of Glass-Aggregate Strength at Optimum Replacement

Age	Mean compressive strength (N/mm^2)				
		Glass-sand Aggregate		Glass-granite Aggregate	
	Control	Glass-sand (20%)	% increment	Glass-granite (10%)	% increment
7 days	10.45	15.05	44.02	12.45	19.14
14 days	12.55	17.05	35.86	14.60	16.33
21 days	15.75	19.55	24.13	18.05	14.60
28 days	19.35	23.65	22.22	20.65	6.72

The compressive strength increment of both concrete specimen follows a linear trend as shown in Figure 3. For the glass-sand concrete, the increment reduces with age but approaches a constant value as the age of concrete increases. The strength increment drops from 24.13% to 22.22% from 21 days to 28 days. Following the nature of percentage increment curve (Figure 3) it comes to a point where the strength increment becomes relatively constant at a relatively high percentage increment. For the glass-granite concrete, there was a drastic reduction in the compressive strength increment from 14.60% at 21 days to 6.72% at 28 days, signifying that the concrete would lose a significant part of its strength as it ages as opposed to the glass-sand concrete. This result indicates that glass-sand aggregate would produce better durable concrete relatively to its glass-granite counterpart.

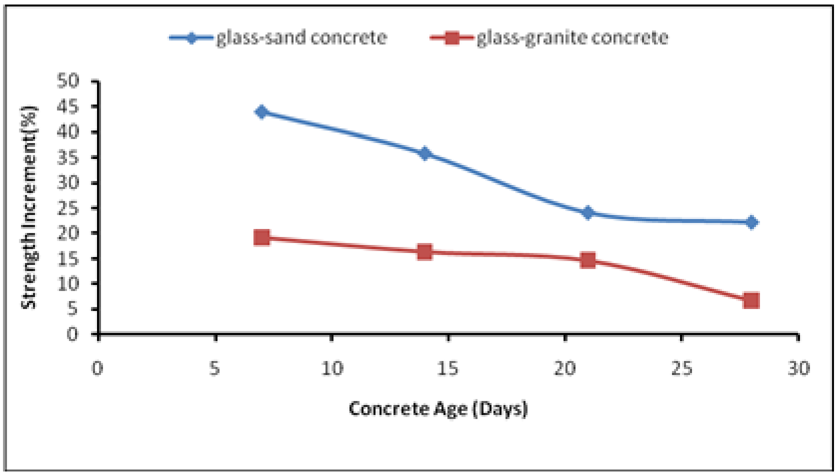

Figure 3: Strength Increment Vs Concrete Age

3.4 Comparative Analysis

The F-statistics is employed for comparison of concrete produced from both methods of concrete production. The hypothesis used here is thus presented.

H_o: Represents no significant difference in the two methods of concrete production with respect to concrete property.

H_1: Represents significant difference in the two methods of concrete production with respect to concrete property.

If F-calculated is less than F-tabulated (from F-distribution Table), accept H_o, otherwise accept H_1.

3.4.1 F-statistics for Workability

The F-statistics for workability of concrete produced from both methods is presented in Table 4.

Table 4: F-statistics Test for Workability

W_F	W_C	$W_F - \bar{W}_F$	$W_C - \bar{W}_C$	$(W_F - \bar{W}_F)^2$	$(W_C - \bar{W}_C)^2$
80.00	85.00	38.625	41.250	1491.891	1701.563
70.00	80.00	28.625	36.250	819.391	1314.063
54.50	61.00	13.125	17.250	172.266	297.563
37.00	45.00	-4.375	1.250	19.141	1.563
29.00	33.50	-12.375	-10.25	153.141	105.063
24.00	20.50	-17.375	-23.25	301.891	540.563
19.50	15.00	-21.875	-28.75	478.516	826.563
17.00	10.00	-24.375	-33.75	594.141	1139.063
$\bar{W}_F$ **= 41.375**	$\bar{W}_C$ **= 43.75**			**Σ= 4030.378**	**Σ = 5926.004**

Where W_F and W_C represents the workability of glass-sand aggregate concrete and glass-granite aggregate concrete respectively.

The sample variance S_f^2 and S_c^2 are determined as follows;

$$S_f^2 = \frac{4030.378}{8} = 503.7973$$

$$S_c^2 = \frac{5296.004}{8} = 740.7505$$

F is calculated as ratio of both sample variances as follows;

$$F = \frac{740.7505}{503.7973} = 1.47$$

At 5% level of significance and degree of freedom of V = 8 – 1= 7

F-tabulated = 3.79, because $F_{cal}<F_{tab}$ (1.47<3.79). Accept H_o, that is, there is no significant difference in workability of concrete produced from both methods.

3.4.2 F-Statistics for 28-Day Compressive Strength

The F-statistics for the 28 days compressive strength of concrete from both methods is presented in Table 5.

Table 5: F-statistics for 28th Day Compressive Strength

C_F^{28}	C_C^{28}	C_F^{28} - $\overline{C}_F^{28}$	C_C^{28} - $\overline{C}_C^{28}$	$(C_F^{28} - \overline{C}_F^{28})^2$	$(C_C^{28}$ - $\overline{C}_C^{28})^2$
19.40	19.85	-0.544	1.899	0.296	3.606
19.65	20.65	-0.294	2.699	0.086	7.285
20.05	19.01	0.106	1.059	0.011	1.121
23.65	18.85	3.706	0.899	13.734	0.808
21.45	18.50	1.506	0.549	2.268	0.301
20.75	17.55	0.806	-0.401	0.650	0.161
19.50	16.00	-0.444	-1.951	0.197	3.806
15.10	13.20	-4.844	-4.751	23.464	22.572
$\overline{C}_F^{28}$ =	$\overline{C}_C^{28}$ =			$\sum(C_F^{28} - \overline{C}_F^{28})^2$	$\sum(C_C^{28} - \overline{C}_C^{28})^2$
19.944	17.951			=40.706	=39.66

Where C_F^{28} and C_C^{28} represents the compressive strength of glass-sand concrete and glass-granite concrete respectively.

The sample variances are,

$$S_f^2 = \frac{40.706}{8} = 5.088$$

$$S_c^2 = \frac{39.66}{8} = 4.9588$$

The F-calculated becomes,

$$F_{-cal} = \frac{5.088}{4.958} = 1.026$$

Because 1.026 < 3.79

Accept H_o: there is no significant difference in the 28 days compressive strength. Stepping through the same algorithm as above, the F-statistics is thus summarised in Table 6.

Table 6: Summary of F-statistic (at 5% level of significance).

Concrete property	Workability	Compressive Strength			
		28 day	21 day	14 day	7 day
F-calculated	1.47	1.026	1.079	1.045	1.134
F – tabulated	3.79	3.79	3.79	3.79	3.79
Decision	No significant diff. (Accept H_o)	No significant diff. (Accept H_o)	No significant diff. (Accept H_o)	No significant diff. (Accept H_o)	No significant diff. (Accept H_o)

In general, there is no significant difference in both methods of concrete production as shown in Table 6 as the F-calculated is less than F-tabulated for all concrete properties.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

From preceding discussions, the following conclusions have been drawn:

1. The optimum replacement of sand with fine glass is 20% while that of granite with coarse glass is 10%.
2. The workability of concrete produced from both methods reduces as the percentage of glass increases.
3. The reduction in workability of glass-sand concrete followed a steady pattern whereas, a sharp reduction in workability is noticed for the glass-granite concrete at 30% replacement level.

4. At optimum replacement levels, glass-sand concrete produced higher compressive strength value in comparison to the glass-granite concrete.
5. The percentage increment in compressive strength reduces as the concrete ages for both concrete.
6. The reduction in strength as concrete ages is more catastrophic for the glass-granite as compared to the glass-sand concrete.
7. Concrete produced from glass-sand concrete is more durable than that produced from glass-granite concrete.
8. From the F-statistics, at 5% level of significance, there is no significant difference between the concrete produced from both methods.
9. Finally, glass as aggregate should be preferably used as fine aggregate. Using glass as coarse aggregate should be limited too very small replacement level.

4.2 Recommendation

1. Further research should be carried out on the effect of glass as aggregate on other concrete properties.
2. Other mix design considerations should be studied on the effects of glass as aggregate.

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