Research Journal of Applied Sciences 3 (4): 311-316, 2008
ISSN: 1815-932X

The Effect of Partial Replacement of Cement with Crushed Waste Glass in Laterized Concrete Production

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Abstract: Technologists, engineers and scientists are continuously on the lookout for materials which can be used as substitutes for conventional materials or which possess such properties that would enable them to be used for new designs and innovations. The waste materials that can be used in making concrete are many and include both organic and inorganic wastes. These materials may be used as a binder material, as partial replacement of conventional Portland cements or directly as aggregates in their natural or processed states. This study examines the effect of crushed waste glass (CWG) when used as partial substitute for cement in laterized concrete. One mix proportion (1:2:4) of cement + CWG, sand, latente and granite coarse aggregate was used with a constant water/cement ratio of 0.65. The effect of crushed waste glass on 2 properties of laterized concrete, namely, compressive strength and workability was investigated. The results showed that the CWG did not enhance the compressive strength of laterized concrete. The compressive strength of the laterized concrete actually decreased as the percentage CWG content increased. Laterized concrete (at 25, 50 and 75% laterite content) showed an initial increase in workability with increases in percentage CWG content in the cement matrix with the maximum slump being obtained at 25% CWG content. Further increases in CWG content resulted in decreased workability. The results also showed that laterized concrete containing 50% laterite and 15% cement replacement with CWG can be used for low/medium cost housing development.

Key words: Crushed waste glass, partial replacement, cement, laterized concrete

INTRODUCTION

Researchers in the last 2 or 3 decades have been driven by the growing need to utilize wastes effectively and find suitable alternatives to cement and/or aggregates for both normal and laterized concrete production. Laterized concrete is concrete in which the sand content is partly or wholly replaced with fine laterite. Large quantities of waste glass, especially in the form of empty bottles, are usually thrown away as garbage and there is likely to be an increase in the quantity of such waste glass as more and more foodstuffs and drinks are sold in glass bottles and containers. This poses a disposal problem which is accentuated by severe restrictions on the pollution of the environment. In the UK for example, the proportion of glass waste in the domestic refuse is estimated to be 9% of the total solid waste while in the USA it is believed to be between 6 and 8% of the total solid waste. Such huge quantities of waste glass are also available in Nigeria and if collected, cleaned and crushed, they can be utilized for the production of laterized concrete.

Samarin (1978) reported encouraging results when he used crushed clean beer bottles of a continuous grading to replace part of the sand and/or Portland cement in an average grade concrete. Refuse glass crushed as fine to medium sized aggregate has been successfully used as replacement of up to 30% of natural aggregate in the manufacture of masonry blocks (Philips *et al*., 1972). Falade (1993) reported some increase in strength when ground broken bottles were used to replace between 5 and 10% of the cement content in the mix. Falade (1990) reported that the use of sawdust ash to replace cement resulted in a reduction in the strength of concrete produced.

Studies carried out by Johnson (1974) on some 34 different concrete mixes which contained crushed glass of up to 20 mm maximum size and using high as well as low alkali cements did not show optimistic results because of excessive expansion which occurred causing surface cracking and appreciable strength reduction. Philips *et al.* (1972) has worked on the possibility of using fly ash to offset the attack by the cement alkalis on the glass with interesting results. He found that the use of 25-30% by weight of cement replacement with fly ash was a likely effective method of improving the dimensional stability and normal rate of strength gain for both high and low alkali cement concretes.

In recent study by the Concrete Materials Team (2004) at Columbia University, it was reported that the use of crushed waste glass as aggregate in concrete was problematic because of the chemical reaction between the alkali in the cement and the silica in the glass. This Alkali Silica Reaction (ASR) creates a gel, which swells in the presence of moisture causing cracks and unacceptable damage of the concrete.

Glass is defined as an organic product of fusion, which has cooled to rigid condition without crystallization. Glass is found in three forms namely, commercial glass, optical glass and special glass. The commercial glass is very rich in silica and it is generally used for commercial purposes, e.g. beer bottle. The optical class has lower silica content and is less readily available than the commercial glass. The special glass is silica free.

In this investigation broken limca bottles were used (collected from a heap dump beside the bottling company). Such broken bottles are in abundance in Nigeria (found mostly in soft drinks and beer bottling companies) as no use has been found for them. It is hoped that this research effort will yield information that would encourage their use as partial replacement of cement and/or sand in concrete production.

MATERIALS AND MEHTODS

Cement: Ordinary Portland Cement (OPC) type with properties conforming to those specified in the relevant British Standard document (BS 12, 1971) was used.

Crushed waste glass: Broken bottles were collected from a heap dump at Limca Industries Limited, Isolo, Lagos. After collection they were washed, dried and later crushed into fine granules with a hammer mill at the Federal Institute of Industrial Research (FIRRO) at Oshodi, Lagos. The granules were then subjected to mechanical sieve analysis. The particles that passed through sieve aperture 600 micron were used in the investigation. The physical as well as the chemical analysis of the crushed waste glass now in powder form, was undertaken in the ceramics Laboratory at FIRRO (Table 1 and 2).

Aggregates: The coarse aggregate was from crushed granite of igneous origin. The particle size range used was 10-20 mm. The sand used was clean, sharp river sand that was free from clay, loam, dirt and organic or chemical matter of any description and was sand passing through 4.75 mm zone of British standard sieve {particle passing through ASTM sieve No, 4 aperture 4.75 mm but retained on ASTM sieve N220 aperture 63 micron}.

Table 1: Chemical properties of cement and Crushed Waste Glass (CWG)

S/No	Parameter	CWG	Cement
1	$Si0_2$	71.86	21.0
2	Na_20	13.72	0.19
3	Ca0	7.54	64.73
4	Mg0	1.63	2.01
5	$A1_20_3$	0.8	5.22

Table 2: Physical properties of materials

	Sample				
Properties	Cement	CWG	Laterite	Sand	Granite
Moisture content %	0.0	0.06	5.0	2.1	1.04
Specific gravity	3.2	2.45	2.61	2.61	2.5

Water: The water used was potable water, which was fresh, colourless, odourless and tasteless water that was free from organic matter of any type.

Laterite: The alteration product of various materials including crystalline igneous rocks, sediments, detrital deposits and volcanic ash. Laterites with high clay content are generally not suitable for laterized concrete because of the difficulty in mixing which may result in low compressive strength values. Laterites containing less than 40% clay content are recommended. The clay content of the laterite used in this investigation was 29.91%.

Sieve analysis: Sieve analysis was carried out for the sand, granite coarse aggregate and fine laterite used in the laterized concrete manufacture. The results are shown in Fig. 1-3.

Mix proportions: One mix ratio, 1:2:4 of cement + CWG, sand plus laterite and granite coarse aggregate was used. A constant water/cement ratio of 0.65 was also used. For the preparation of the laterized concrete specimens the percentage of sand by weight of the total fine aggregate was varied in steps of 25% up to a maximum of 100% corresponding to normal concrete. The percentage of crushed waste glass by weight of the total cement content was varied in steps of 5% up to a maximum of 35%.

Preparation and casting of test specimens: A total of 12 laterized concrete cube specimens were prepared for each proportion of laterite in the cement mix. The batching of the materials was by weight. The cube specimens were cast by filling each cube mould in 3 layers, each layer having been compacted normally with 25 blows from a steel rod of 25 mm diameter before the next layer was

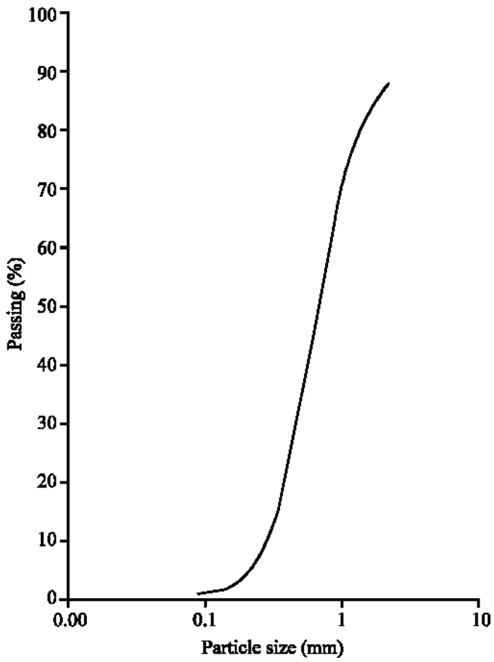

Fig. 1: Sieve analysis of sand

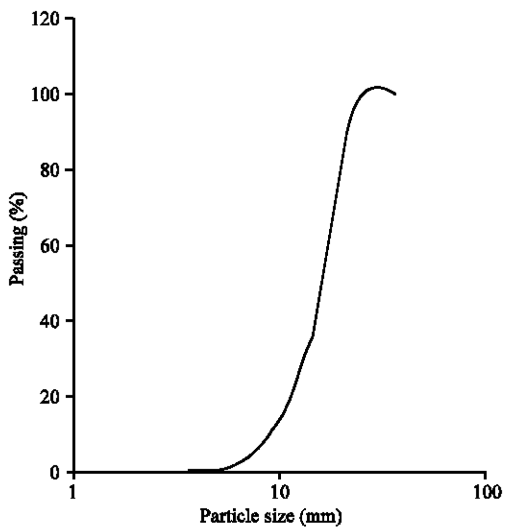

Fig. 2: Sieve analysis of granite

poured. After casting the specimens were covered with jute sack for 24 h so as to set and harden before they were removed from the moulds. The cubes were then transferred to a curing tank containing clean water where they were kept until the day for their testing. The curing water was left at room temperature. The workability (using slump test) of the fresh laterized concrete was determined immediately after the final mixing.

Testing of test specimens: The cubes were tested at ages 7, 14, 21 and 28 days using a manual 1560 KN

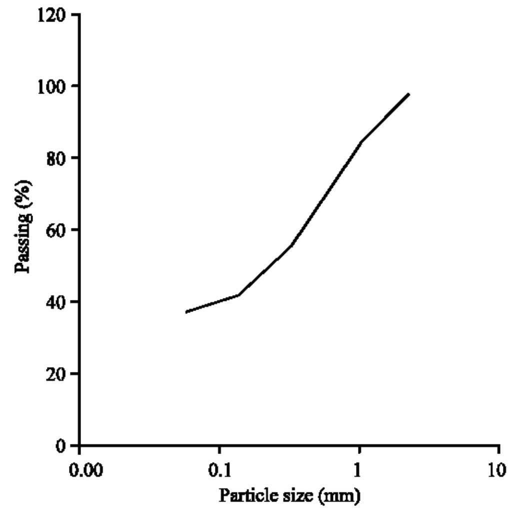

Fig. 3: Sieve analysis of laterite (wet analysis)

Brudensberg Hydraulic Compressing Machine. Three specimens were tested at each age and the values of the crushing load were averaged and used to determine the mean strength for each group.

RESULTS AND DISCUSSION

The results of the effect of replacing cement with crushed waste glass on the workability and compressive strength of laterized concrete are presented both in tabular (Table 3 and 4) and in graphical form. Figure 4 shows the variation of slump of the laterized concrete specimens with the percentages of the crushed waste glass used in the investigation. Figure 5-9 show the variations of the compressive strength with percentage crushed waste glass used in the mix.

Effect on workability: The workability of the mixes (25, 50 and 75% laterite content) increased with the percentage CWG content in the matrix. The highest value of slump was obtained at a percentage CWG content of 25%. As the CWG content in the mix increased the slump decreased. The initial increase in slump up to 25% CWG content may be attributed to the reduction in cement available in the mixes and the low water absorption capacity of CWG. The decrease in slump with increase in CWG content in the mix may be due to the fact that CWG has a lower specific gravity (2.45) than that of the cement (3.20) that it replaces. Consequently, for a given weight of cement a greater quantity of CWG will be required to maintain the equivalent weight (of cement) thereby, increasing the net specific surface area to be wetted. Results also showed that a collapse slump was obtained for the laterized concrete with 0% laterite content

Table 3: Variation of the density of laterized concrete with crushed waste glass

Percentage laterite	Age (Days)	Percentage of crushed waste glass							
		0	5	10	15	20	25	30	35
100	7	2459	2430	2400	2430	2459	2430	2430	2430
	14	2430	2459	2400	2400	2430	2400	2400	2400
	21	2430	2489	2459	2430	2400	2400	2400	2400
	28	2430	2459	2430	2400	2489	2400	2400	2400
75	7	2489	2489	2456	2430	2430	2459	2430	2430
	14	2430	2459	2430	2459	2489	2430	2459	2430
	21	2430	2459	2519	2459	2430	2430	2400	2400
	28	2453	2430	2489	2430	2459	2400	2430	2400
50	7	2489	2489	2459	2489	2459	2489	2430	2430
	14	2459	2489	2459	2459	2430	2459	2459	2459
	21	2459	2459	2489	2459	2489	2430	2430	2430
	28	2519	2519	2489	2459	2459	2430	2430	2430
25	7	2519	2548	2519	2489	2519	2459	2489	2459
	14	2548	2489	2519	2519	2459	2459	2519	2459
	21	2519	2519	2519	2489	2489	2489	2459	2459
	28	2489	2489	2489	2489	2489	2459	2489	2489
0	7	2519	2519	2489	2519	2548	2578	2548	2489
	14	2578	2519	2578	2519	2548	2548	2548	2489
	21	2548	2519	2548	2548	2307	2519	2548	2459
	28	2519	2548	2489	2578	2578	2578	2519	2489

Table 4: Compressive strength results of laterized concrete with crushed waste glass

Percentage laterite	Specimen age in days	Compressive Strength (N Mn^{-2}) Cwg (%)							
		0	5	10	15	20	25	30	35
0	7	16	16.5	16	15	13	12.5	11.0	10.5
	14	17	18	17.5	17	16.6	16	15.5	15
	21	17.2	18.4	18.0	17.8	18.2	18.0	16	16.2
	28	20	23	22	19.8	19.5	19.3	17.2	17.0
25	7	15	15	15	15	14.8	14.0	12.0	9.0
	14	17	16.5	16.6	16.2	16.4	15.8	14.8	14.0
	21	20	19.8	18.4	18.4	18.0	17.6	17.4	17.2
	28	22	22	21	21	20.6	20.0	19.8	19.4
50	7	19.8	17.0	16.0	15.0	13.0	12.8	11.6	10.0
	14	21	19	17	16	15	14.8	14.4	14.2
	21	23	20	19.0	18.8	18.4	18.2	18.0	18.0
	28	24	23	21	20	19.8	18.0	17.8	17.8
75	7	15	14.5	14.0	13.8	13.0	12.0	11.8	8.0
	14	16.0	15.8	15.6	15.4	15.0	14.6	14.8	10.0
	21	17.0	16.2	16.0	15.8	15.4	14.4	14.6	12.0
	28	17.8	17.4	17.0	16.8	16.0	15.8	15.4	12.8
100	7	8.0	7.8	7.0	6.8	6.0	6.0	5.6	3.8
	14	9.8	9.6	8.8	8.6	8.4	8.4	7.8	6.6
	21	13.0	12.8	12.6	12.4	11.4	11.8	11.4	11.0
	28	15.0	14.8	14.4	14.0	14.0	13.8	13.6	13.0

(normal concrete) for all the various percentages of CWG content. This could be attributed to the fact that the mixes were mostly stiff and difficult to work.

Effect on compressive strength: The results of the compressive strength tests are shown in Fig. 5-9. The results showed that the maximum strength of 23.5 N mm^{-2} was obtained at a 0% CWG content and a laterite content of 50%. As the percentage CWG content in the cement matrix increased the compressive strength was found to decrease. The slump tests carried out on the mixes with 0% laterite content revealed that the mixes were too wet and therefore prone to segregation, hence, the low compressive strength values obtained. In a similar manner, the mixes at 75 and 100% laterite content were too stiff to enable adequate compaction to be carried out, hence, the low compressive strength values obtained.

Figure 5-9 showed that the compressive strength values decreased with increase in the percentage CWG content except for the control mix (0% laterite content) where an increase in compressive strength was obtained at 5% CWG content. The decrease in compressive strength is attributable to the fact that the partial replacement of cement with CWG caused a reduction in the quantity of cement available for the hydration process, with a consequent reduction in the formation of the strength producing compounds- calcium silicate hydrates. In addition, the observed low strength for

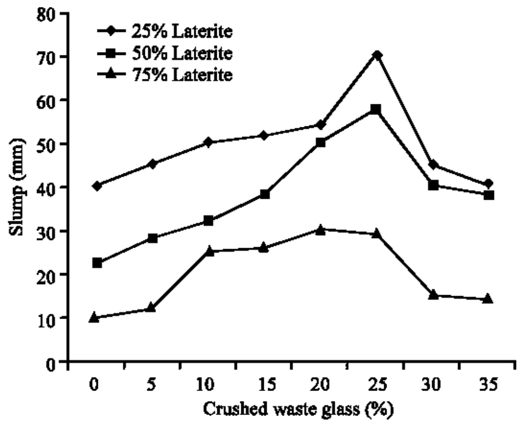

Fig. 4: Variation of slump of laterized concrete with different percentages of crushed waste glass

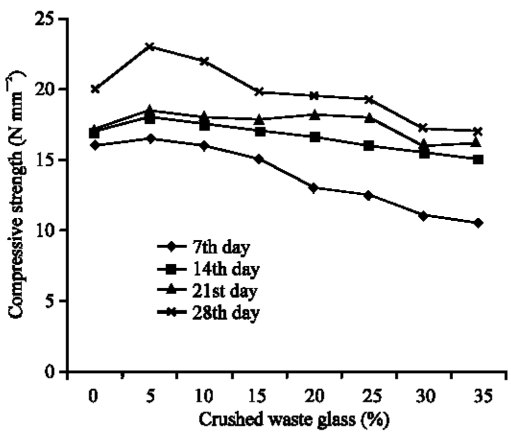

Fig. 5: Variations of compressive strength of laterized concrete cubes with different percentages of crushed waste glass (0% Laterite)

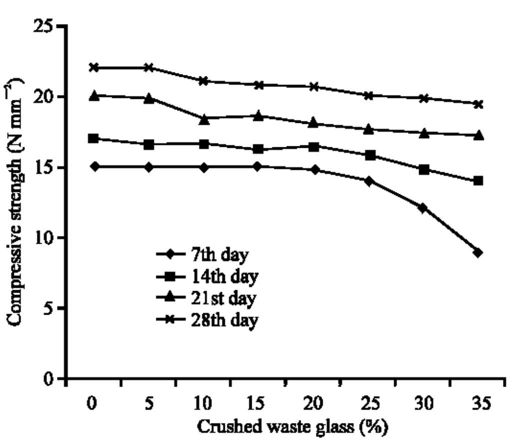

Fig. 6: Variations of compressive strength of laterized concrete cubes with different percentages of crushed waste glass (25% Laterite)

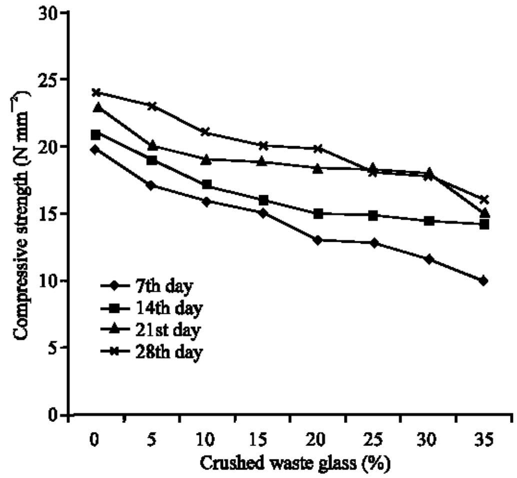

Fig. 7: Variations of compressive strength of laterized concrete cubes with different percentages of crushed waste glass (50% Laterite)

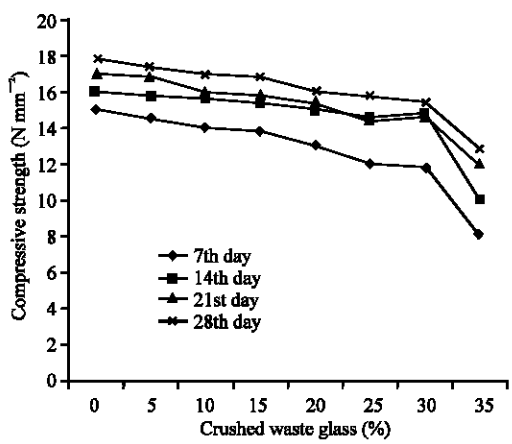

Fig. 8: Variations of compressive strength of laterized concrete cubes with different percentages of crushed waste glass (75% Laterite)

laterized concrete containing high percentage of crushed waste glass in the early ages may be due to the fact that pozzolans are known to exhibit low reactivities at early ages only to develop higher strength later (Chong, 1977). A careful examination of Fig. 7 shows that the compressive strength values of the laterized concrete with 50% laterite content were actually higher than the corresponding values for normal concrete (0% laterite content) up to 15% cement replacement with CWG. Since, laterite is cheaper than sand and crushed waste glass is cheaper than cement, laterized concrete with cement partly replaced with CWG is a material that should be considered for low/medium cost housing development.

Effect on density: Table 3 shows the density of the laterized concrete used in the investigation. A careful

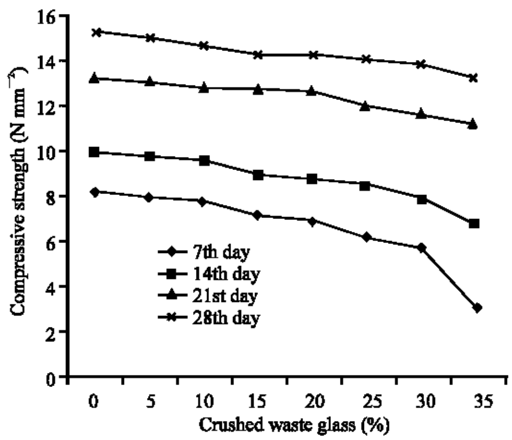

Fig. 9: Variations of compressive strength of laterized concrete cubes with different percentages of crushed waste glass (100% Laterite)

examination of the table shows that the density of laterized concrete compares favourably with that of plain normal concrete (0% laterite content). This confirms the results of previous works (Balogun *et al.*, 1984; Oyekan, 1997) that laterized concrete is not a structural lightweight concrete.

CONCLUSION

The main conclusions derived from this investigation are as follows:

- Crushed waste glass improved the workability of laterized concrete up to 25% CWG content, after which the workability decreased as the percentage CWG content in the mix increased.
- Crushed waste glass did not enhance the compressive strength of laterized concrete. The compressive strength actually decreased as the percentage CWG content increased in the cement matrix.
- The density of laterized concrete containing crushed waste glass compares favourably with that of normal concrete indicating that laterized concrete is not a lightweight concrete.
- Laterized concrete manufactured with 50% laterite content and 10% cement replacement with CWG can be used for low/medium housing development.
- It is recommended that strength properties of laterized concrete be investigated using green and white bottles separately and that other mix proportions be used in the investigation.

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