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Influence of Water/Cement Ratios and Mix Proportions on Workability and Characteristic Strength of Concrete Containing Laterite Fine Aggregate

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This paper examines the variation of workability and characteristic strength of laterized concrete (concrete containing laterite fine aggregate instead of sand) with different water/cement ratios and mix proportions. Four mixes of cement : lateritic soil : crushed granite were considered, namely $1:1:2$, $1:1\frac{1}{2}:3$, $1:2:4$ *and* $1:3:6$. *Two methods—slump and compacting factor tests were used for the workability while the conventional cube test was used for the compressive strength. Cubes (100 mm) were made, water-cured at* $21+2°C$ *and tested at 7 and 28 days. The results showed that the water requirement for a mix increases with increase in laterite/cement ratio. Associated with slump test are: zero, true, partial collapse and collapse slumps. The strength decreases with increase in laterite/cement and water/cement ratios. It was further found that the workability decreases with increase in laterite/cement ratio. The results indicated that the well established variations of workability and compressive strength of normal concrete with water/cement ratios are valid for laterized concrete.*

INTRODUCTION

THE basic and most utilized materials for concrete are cement and aggregates (fine and coarse). The use of lateritic soils as building materials is becoming widely accepted among the low-income earners in the rural as well as the urban areas of Nigeria. This class of people uses lateritic soils for mud walls, mortars, components of structural elements and masonry units without much regard for the engineering strength and performance characteristics of the materials. Walls of a large percentage of residential houses in rural areas have been built and continue to be built with 'worked' lateritic soils in different forms, with or without cement stabilization. These soils are also used as sub-grade materials for rural roads. Their use as a substitute for sand in concrete has been advocated as a welcome idea. This has geared researchers to investigate the engineering properties of both stabilized and unstabilized lateritic soils. Adepegba [1] established that the strength properties of concrete in which sand is replaced with laterite fines compare favourably with those of normal concrete. In another study by Adepegba [2], it was reported that water affects the compressive strength of laterized concrete. These materials, apart from being tropical in nature and readily available at jobsites, do not require to be washed like sand because they contain little or no organic material that can affect chemical reaction with cement during the formation of concrete. Stabilization with cement, lime, bitumen, etc. has been found by Ola [3] to be an effective means of improving engineering properties of lateritic soils for both road construction and low-cost housing. Ola [4] found that less than 50% of the cement required for the temperate zone soils is required for efficient stabilization of lateritic soils for road subgrade work. The engineering properties of some Eastern Nigeria laterites for possible uses as aggregate in concrete have been studied by Madu [5, 6] with the results that lateritic aggregates are good materials for road chippings and concrete aggregates but with slightly inferior results to those obtained from igneous aggregates. In a study by Lasisi and Ogunjimi [7], it was reported that the location from which lateritic soils are procured, particularly the topographic conditions, affects the strength properties of laterized concrete. Falade [8] established that the differences in strength values are statistically insignificant irrespective of the locations from which the samples are procured.

This report forms part of research efforts being made to develop the design parameters for the effective structural applications of lateritic soils in concrete.

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MATERIALS AND EXPERIMENTAL PROCEDURE

The lateritic soil used for this research work was collected from a borrow pit along Ife–Ibadan road. The large lumps were crushed and sieved. The particles passing 2.36 mm and retained on 0.30 mm openings were used. Wet sieving and sedimentation tests were carried out to determine the grain size distribution for the laterite. The coarse aggregate is from crushed granite of igneous origin. The particle size ranged from 10–19 mm. Figure 1 shows the particle size distribution curves of the fine and coarse aggregates considered.

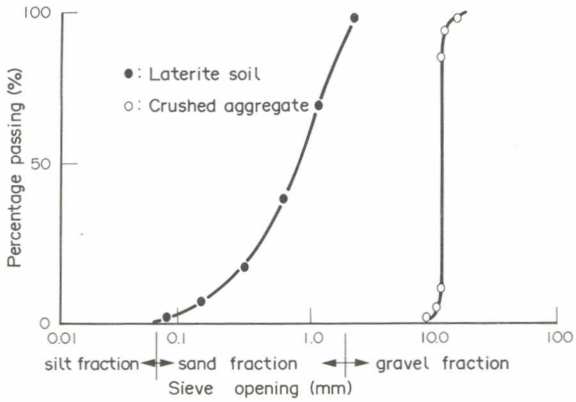

Fig. 1. Results of sieve analysis of the laterite soil sample and crushed aggregate.

The cement is Ordinary Portland Cement from the West African Portland Cement Company, Ewekoro in Ogun State of Nigeria whose properties conform with BS 12 [9].

Four mix proportions (by weight) of cement : lateritic soil : crushed granite were considered, namely 1:1:2, 1:$1\frac{1}{2}$:3, 1:2:4 and 1:3:6. The water/cement ratio varied with each mix, for 1:1:2 from 0.3–0.90, 1:$1\frac{1}{2}$:3 from 0.52–1.12, 1:2:4 from 0.65–1.35 and 1:3:6 from 0.90–1.00.

Cubes (100 mm) were made in accordance with BS 1881 [10], water-cured at 21 ± 2°C and tested at 7th and 28th days. The specimens were tested on 600 kN Avery Denison, using a loading rate of 120 kN/min. The slump and compacting factor tests were carried out on fresh concrete immediately after mixing.

RESULTS AND DISCUSSION

The effect of water/cement ratio and mix proportion on the characteristic strength and workability of laterized concrete is summarized in Fig. 2 and Table 1. Approximate optimum water/cement ratios of 0.50 for 1:1:2, 0.62 for 1:$1\frac{1}{2}$:3, 0.75 for 1:2:4 and 1.00 for 1:3:6 were obtained. The corresponding 28-day characteristic strengths at those ratios are 22.8 Nmm^{-2} for 1:1:2, 17.5 Nmm^{-2} for 1:$1\frac{1}{2}$:3, 15.0 Nmm^{-2} for 1:2:4 and 8.7 Nmm^{-2} for 1:3:6. The slump is zero for all the mixes at the same w/c ratios while the compacting factor values are 0.62 for 1:1:2, 0.62 for 1:$1\frac{1}{2}$:3, 0.59 for 1:2:4 and 0.56 for 1:3:6 (Table 1). In Fig. 2 for 1:1:2 mix, at w/c ratio lower than the optimum, reduced strength, zero slump and higher compacting factor values were obtained. At w/c ratios higher than the optimum, strengths decreased while slump and compacting factor values increased. The trend is also observed in other mixes (Table 1). When the w/c ratio is lower than the lower limit for each mix (0.4 for 1:1:2, 0.52 for 1:$1\frac{1}{2}$:3, 0.65 for 1:2:4 and 0.90 for 1:3:6), a too dry mix that could not be compacted successfully with the tamping rod recommended for the standard method of preparing concrete test specimens results. When the upper limit (0.9 for 1:1:2, 1.12 for 1:$1\frac{1}{2}$:3, 1.35 for 1:2:4 and 1.80 for 1:3:6) is exceeded, the mix obtained is too wet, resulting in segregation. At collapse slump, the value of compacting factor is close to unity. This can be attributed to the fact that gravel displaced the cement/laterite grout after falling down into the cylinder and since gravel has higher specific gravity than the grout, the weight of the concrete that fell into the cylinder was thus closer to the weight of the fully compacted concrete. The increase in slump is due to excess water in the mix. The decrease in strength may be attributed to increase in the quantity of water entrained in the hardened cube specimens (Falade [11]).

The results indicate that laterized concrete mixes containing high aggregate content require more water to attain the same level of workability than those with less aggregate content. For example 1:1:2 mix attained a

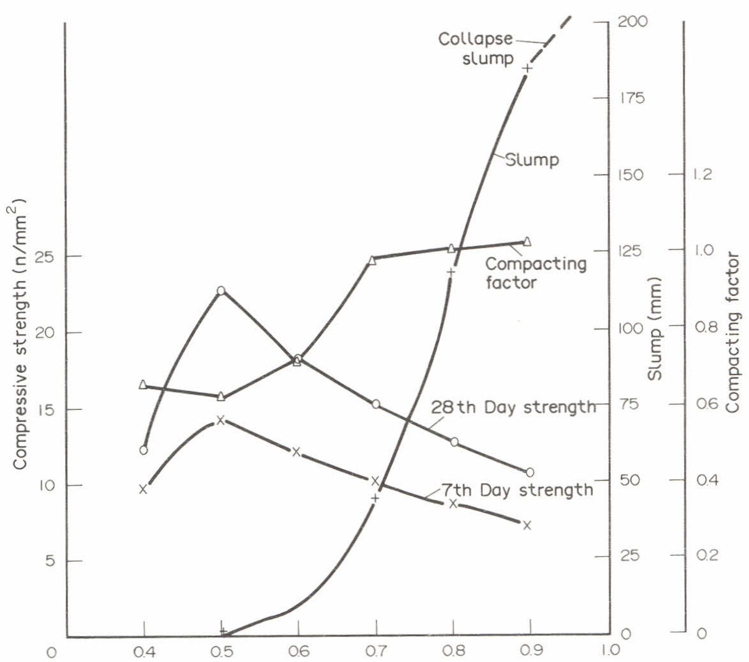

Fig. 2. Variation of compressive strength slump and compacting factor with water/cement ratios (1:1:2 mix).

Table 1. The results of workability and compressive strength tests

Mix proportions	Water/cement ratio	Slump (mm)	Compacting factor	7 day strength (N/mm^2)	28 day strength (N/mm^2)
1:1:2	0.40	0.00	0.66	9.7	12.3
	0.50†	0.00	0.62	14.2	22.8
	0.60	10.50	0.72	12.0	18.3
	0.70	45.00	0.98	10.2	15.2
	0.80	119.00	0.98	8.7	12.6
	0.90	185.00*	0.99	7.4	10.6
1:1½:3	0.52	0.00	0.66	8.0	11.0
	0.62†	0.00	0.62	11.8	17.4
	0.72	5.50	0.65	10.5	15.6
	0.82	21.00	0.79	9.1	13.9
	0.92	60.00	0.98	7.9	11.8
	1.02	121.00	0.99	6.6	9.8
	1.12	183.00*	0.99	5.5	7.9
1:2:4	0.65	0.00	0.66	6.5	9.8
	0.75†	0.00	0.59	9.2	15.0
	0.85	4.00	0.60	8.5	12.0
	0.95	15.00	0.68	7.3	10.7
	1.05	33.00	0.80	5.9	9.6
	1.15	70.00	0.95	4.9	7.2
	1.25	129.00	0.97	4.5	6.1
	1.35	184.50*	0.99	3.3	5.6
1:3:6	0.90	0.00	0.59	4.0	5.9
	1.00†	0.00	0.56	6.5	8.7
	1.10	1.50	0.58	5.4	7.7
	1.20	6.00	0.64	4.5	6.3
	1.30	13.50	0.76	3.8	5.8
	1.40	30.00	0.86	3.2	5.3
	1.50	54.00	0.93	2.6	4.6
	1.60	93.00	0.97	2.4	4.3
	1.70	141.00	0.98	2.3	4.0
	1.80	185.00*	0.99	2.1	3.7

* Collapse slump.
† Approximate optimum water/cement ratio.

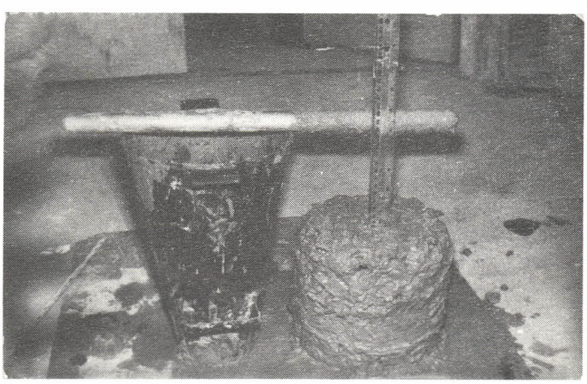

Fig. 3. Partial collapse slump.

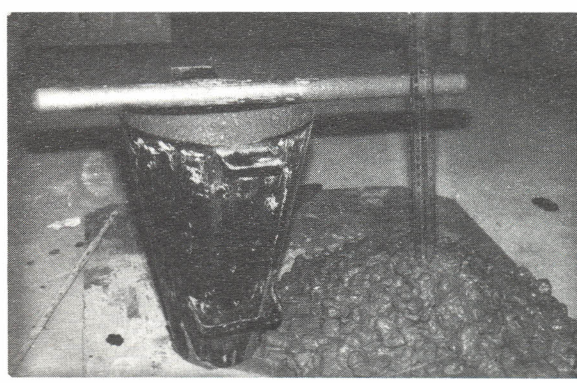

Fig. 4. Collapse slump.

collapse slump at w/c ratio of 0.90, 1:1½:3 at 1.12, 1:2:4 at 1.35 and 1:3:6 at 1.80. This may be due to increase in specific surface area of the aggregate to be wetted before obtaining a workable mix of concrete with high aggregate content. Like normal concrete, four types of slump are associated with laterized concrete—zero, true, partial collapse (Fig. 3) and collapse (Fig. 4). The partial collapse is intermediate between true and collapse slump, a position similar to shear slump in normal concrete. However, rather than any part of the specimen shearing off, the upper half was seen collapsed and settled on the lower half which appeared to be still intact (Fig. 3). This phenomenon may be due to the cohesive forces between the particles of the lateritic soil. Table 2 shows the range of values for both slump and compacting factor for normal concrete work and the use for which each range is suitable. This classification can also be applied to laterized concrete work.

On the average, the compressive strength at 7 days was about 68% of the compressive strength at 28 days.

CONCLUSIONS

The results of this study show that:

(i) Four types of slump are associated with laterized

Table 2. Workability, slump and compacting factor of concrete with 19 or 38 mm maximum size of aggregate*

Degree of workability	Slump (mm)	Compacting factor: Small apparatus	Compacting factor: Large apparatus	Use for which concrete is suitable
Very low	0–25	0.78	0.80	Road vibrated by power operated machines
Low	25–50	0.80	0.87	Road vibrated by hand operated machines, mass concrete foundations without vibration
Medium	50–100	0.92	0.935	Normal reinforced concrete manually compacted and heavily reinforced sections with vibration
High	100–175	0.95	0.9	For section with congested reinforcement normally suitable for vibration

* *Properties of Concrete* (Neville 1981).

concrete, namely zero, true, partial collapse and collapse.

(ii) The water requirement increases as laterite/cement ratio increases for a given mix proportion.

(iii) For a given water/cement ratio, when laterite/cement ratio increases strength and workability decrease. However, with increase in water/cement ratio strength decreases and workability increases.

(iv) The well established variation of workability and strength with water/cement ratio for normal concrete is valid for laterized concrete.

It is recommended that further work be carried out on workability and strength to assess the possibility of predicting 28 day strength from slump test.

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