Re-Investigation of the Compressive Strength of Ordinary Portland Cement Concrete and Lime Concrete

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Abstract: ***This paper presents the experimental results of the re-investigation of the compressive strength of ordinary portland cement (OPC) concrete and lime concrete (LC) using five selected mix ratios. Materials used in concrete production were ordinary portland cement, hydrated lime, granite chippings as coarse aggregates and river sand for fine aggregate. Optimum values of compressive strength recorded for OPC concrete at 7 days and 28 days of curing were 11.55N/mm^2 and 26.96N/mm^2 respectively. These corresponded with mix numbers M_1 and M_5 respectively. Also, optimum values of compressive strength for LC at 28 days and 90 days of curing were 6.12N/mm^2 and 13.15N/mm^2 respectively and both corresponded to mix number M_5. The results obtained showed that the compressive strengths at 90 days curing for LC are approximately half of the compressive strength values of OPC concrete at 28 days. Compressive strength values at 90 days for the LC were close to that of the 7 days strength values for OPC concrete. The compressive strength values of LC increased with increasing curing age which informs non-deterioration of concrete. Compressive strengths at 7 days curing of LC showed no results of strength gain. The initial and final setting time for OPC paste were 60mins and 430mins respectively, while that of lime paste were 2880mins (2 days) and 4320mins (3 days) respectively. Grain size distribution for the river sand and granite chippings, showed that the fine aggregates used was poorly graded containing non uniform range of particles, while the coarse aggregate used was poorly graded and contains uniform range of particles. The use of lime concrete for constrcuction purpose results to very low strength of the concrete, therefore this concrete will require the addition of other pozzolanic material to increase its rate of gain of strength.***

Keywords: Compressive strength, Ordinary portland cement (OPC), Lime concrete (LC).

1. Introduction

Conventional concrete is a mixture of cement, sand, aggregates and water [14]. The overall relevance of concrete in virtually all civil engineering practice and building construction works cannot be over-emphasized. According to [12], concrete is a basic material that will continue to be in demand far into the future. The cement industry, like the rest of the construction industry, is facing unprecedented challenges relating to energy resources, CO_2 emissions and the use of alternative materials [12]. The cost of energy is rising inexorably as fuel sources deplete. A concrete made from a mixture of lime, sand, gravel and water is said to be a lime concrete [9]. Concrete made with lime cement is well known for more than 5000 years old. Before the advent of portland cement in 1824, lime was the predominant binder used for making renders, mortar, and concrete. Lime pozzolans were used by the Greeks and Romans to build walls, floors, baths, aqueducts, vaults and domes [6]. Signs of its usuage can be easily found after surveying different archaeological sites. An example is the Colosseum or flavian amphitheatre. Its construction started in 75AD and was completed in 80 AD [8]. The part of this structure made from lime concrete is still standing till today. Lime is an industrial product obtained by calcination of limestone in a lime kiln [5]. Lime concrete provides good bases to bear sufficient loads and also provide certain degree of flexibility. It adjusts very well when it is in contact with the surface. It also exhibits certain degree of water proofing and thus prevents subsoil dampness on floors and walls. It can be made easily and can be available at much cheaper rates. It also resists weathering effects and is very durable [9]. Its disadvantage is that it takes greater time for it to gain strength and does not harden under water. But with the growing concern of global pollution from CO_2 emission during portland cement manufacture, many researchers and engineers are seeking and developing new materials that are more environmentally friendly and the use of lime as binder in concrete making has been re-awakened.

2. Literature Review

Many researchers have carried out works on the use of lime as a binder in concrete making. [7] partially replaced cement with lime and noted that there was a linear decline in strength with a linear increase in the relative percentage of lime to concrete. [11] used lime putty as a binder in concrete and discovered that the lime putty addition had a positive effect on the properties of concrete that contained pozzolans. [13] replaced cement with high lime fly ash in producing concrete and reported that the strength of the concrete was improved. [5] investigated on the effects of the presence of free lime nodules in concrete. They reported that the expansion that accompanies the transformation of calcium oxide (CaO) into hydrated lime $Ca(OH)_2$, induces stresses and strains. They further recommended that the minimum required concrete cover, necessary to avoid the development of the “pop-out” phenomenon be estimated as half the diameter of the inclusion.

The increase in the demand of concrete for construction works has also resulted to an increase in the demand for the production of cement, leading to a significant source of global CO_2 emission. As a result of this need, possible ways of using environmentally friendly, and energy saving materials are being researched. Thus, the purpose of this study is to re-investigate the compressive strength of lime concrete and OPC concrete using five selected mix ratios, in other to provide data on the compressive strength of lime concrete without the inclusion of any pozzolanic material and compare the strengths obtained to those of OPC concrete.

3. Materials and Method

3.1 Materials

Locally available materials were used to prepare concrete cubes in this work. These include Dangote cement, a brand of ordinary portland cement, which conforms to the requirements of [2], hydrated lime was purchased from Dugbe, in Ibadan, Oyo state, river sand, obtained from Otamiri river in Owerri, Imo State, granite chippings obtained from Setraco quarry site at Uturu in Abia State and water, obtained from municipal water supply. Concurrently, grain size distribution of the fine and coarse aggregates were determined by sieve analysis test. This is a process of dividing a sample of aggregate. Two samples of air dried aggregates (sand and granite chippings) were graded by shaking or vibrating a nest of stacked sizes of sieves, with the largest sieve at the top for the material retained to be coarse compared to the sieve but finer than the sieve above. The particle size distributions are shown in Fig 1 and Fig. 2.

In order to evaluate the setting time of the cement paste, initial and final setting time test of the OPC paste and lime paste were also carried out using the vicat apparatus. This test was conducted according to [3].To determine the initial setting time, a 1mm diameter needle attached to the plunger of the vicat apparatus and acting under the self-weight of the plunger was used to penetrate a paste of standard consistency placed in a special mould. When the paste stiffens such that the needle can’t penetrate more than a depth of 33mm to 35mm, initial setting has occurred. A similar needle fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5mm in diameter and set between 0.5mm between the tips of the needle was used in determining the final setting time. Final setting occurred when upon lowering, the attachment gently cover the surface of the test block, and the centre of needle made an impression, while the circular cutting edge failed to do so. The initial and final setting times are given in Table 3. The mix proportions of these constituent materials of concrete are shown in Table 4.

3.2 Methods

Five different mix ratios were selected for this investigation, and they include; 1:3:6; 1:2:4; 1:2.5:5; 1:1.5:3 and 1:1:2 with water cement ratios of 0.6, 0.57, 0.55, 0.53, and 0.50 respectively. Batching was by weight and mixing was done manually on a smooth concrete pavement. Required proportion of OPC or hydrated lime was mixed with the fine aggregate-coarse aggregate mix, also at required proportions. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure homogeneity. The workability of the mixtures were measured using the slump test and wet density was determined. Thirty concrete cubes were prepared using OPC concrete and another thirty using lime concrete (LC). This gave a total of sixty concrete cubes. The OPC specimens were cured in open water tanks for 7 days and 28 days while the LC specimens were cured by sprinkling of water for 28 days and 90 days. These specimens were crushed in accordance to [4] to determine their failure loads. The compressive strength of concrete was then calculated from the formula:

$$F_{cu} = P/A \qquad (2.1)$$

where, P = Crushing load (N) ; A = Surface area of the specimen (mm^2); F_{cu} = Compressive strength of concrete (N/mm^2)

4. Results and Findings

Table 1 and Table 2 show the results of the seive analysis conducted on the river sand and granite chippings. The shape of the grain distribution curve indicates the type of soil [1]. The distribution graph which shows the percentage passing (%) against sieve size (mm) is analyzed based on the two important numerical measure which are Coefficient of uniformity (C_u) and Coefficient of curvature (C_c).

$$\text{Coefficient of uniformity (Cu)} = \frac{D_{60}}{D_{10}} \qquad (3.1)$$

Where; D_{10} = The effective particle size with 10% of the sample by weight smaller than its size and

D_{60} = The effective particle size with 60% of the sample by weight smaller than that size

$$\text{Coefficient of curvature (Cc)} = \frac{(D_{30})^2}{D_{10} X D_{60}} \qquad (3.2)$$

D_{30}= The effective particle size with 30% of the sample by weight smaller than that size

According to the unified soil classification system for gravel to be well graded, it must satisfy the following conditions: Cu > 4 and 1 < Cc < 3. If both of these conditions are not met, the gravel is classified as poorly graded. Also, for sand to be classified as well graded, the following condition must be satisfied; Cu ≥ 6 and 1 < Cc < 3. If both criteria are satisfied, sand is classified as well graded, if not, it is poorly graded. Cu and Cc for the river sand were calculated to be 3.24 and 1 respectively. This means that the sand is poorly graded. This sand also falls under zone 1 i.e. it is coarse sand [10]. Similarly, Cu and Cc for the granite chippings were calculated to be 1.4 and 1.02 respectively. Granite chippings used is poorly graded and contains uniform range of particle sizes.

Table 3 presents the results of initial and final setting time test of the Dangote cement paste and hydrated lime paste used for the study. The results shows that the initial setting time for the OPC paste is 1 hour while the final setting time was 430 mins (i.e. approximately 7 hours). The initial and final setting time for the hydrated lime paste is 2880mins (i.e. 48 hours) and 4320 mins (i.e. 72 hours) respectively.

Tables 1: Particle size distribution of Otamiri river sand

Sieve size(mm)	Mass of sieve (g)	Mass of sieve & sample (g)	Mass of Sand Retained (g)	Mass of Sand passing (g)	% Passing
4.75	374.38	405.18	30.8	969.2	96.92
2.00	422.78	507.06	84.28	884.92	88.492
1.40	373.09	514.50	141.41	743.51	74.351
0.85	328.04	645.02	316.98	426.53	42.653
0.42	319.21	612.74	293.53	133	13.3
0.212	317.61	406.36	88.75	44.25	4.425
0.150	268.47	307.09	38.62	5.63	0.565
Pan	371.29	376.92	5.63	0	0

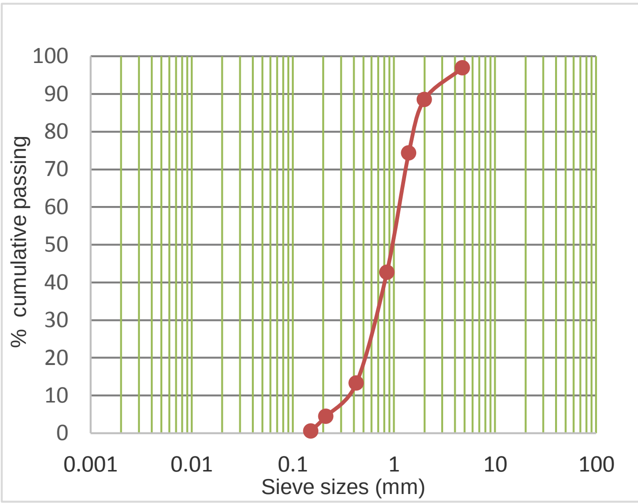

Fig 1: Graph of percentage cumulative passing of river Sand vs. sieve sizes (mm)

Table 2: Particle size distribution o/f granite chippings.

Sieve size (mm)	Mass of sieve (g)	Mass of sieve & sample (g)	Mass of chippings Retained (g)	Mass of chippings passing (g)	% passing
22.40	511.60	0	0	1000	100
19.00	465.51	585.72	120.12	879.88	87.988
14.00	426.51	1087.29	660.78	219.1	21.91
13.20	445.51	545.54	100.12	118.98	11.898
10.00	445.42	485.04	70.17	48.81	4.881
9.50	414.87	470.45	29.12	19.69	1.969
6.70	467.06	480.23	13.17	6.52	0.652
2.80	422.15	425.91	3.76	2.76	0.276
Pan	370.72	373.48	2.76	0	0

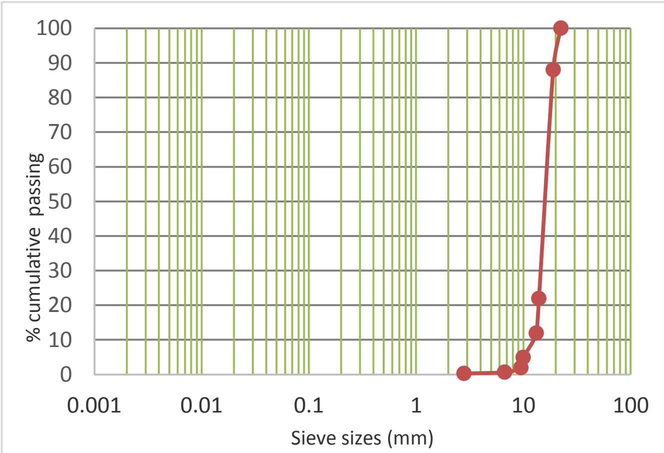

Fig 2: Graph of percentage cumulative passing of granite Chippings (%) vs. sieve sizes (mm).

Table 3: Setting time of OPC paste and hydrated lime paste

Paste	Initial setting time (mins.)	Final setting time (mins.)
OPC	60	430
Hydrated lime	2880	4320

The mix proportions used for preparing concrete cubes are presented in Table 4. These proportions are used for the OPC concrete as well as the LC.

Table 4: Mix Proportion used for preparing concrete cube for compressive strength test.

S/ No	Mix No.	Mix ratio	Water-cement ratio	Water (Kg)	Cement (OPC/hydrated lime) (kg)	Sand (kg)	Chippings (kg)
1.	M_1	1:3:6	0.60	0.84	1.40	4.20	8.40
2.	M_2	1:2:4	0.57	1.14	2.00	4.00	8.00
3.	M_3	1:2.5:5	0.58	0.91	1.65	4.12	8.23
4.	M_4	1:1.5:3	0.53	1.30	2.55	3.82	7.63
5.	M_5	1:1:2	0.50	1.75	3.50	3.50	7.00

Table 5 presents the experimental results of compressive strengths results obtained for 7days and 28 days OPC concrete and also, 28days and 90 days lime concrete. The results showed that the strength of the 28 day OPC concrete gave the highest values of compressive strengths. Optimum values of compressive strength recorded for OPC concrete at 7 days and 28 days were 11.55N/mm^2 and 26.96N/mm^2 respectively, corresponding to mix ratios 1:3:6 at water cement ratio 0.6 and 1:1:2 at water-cement ratio 0.5. Optimum compressive strengths recorded for the lime concrete at 28 days and 90 days were 6.12N/mm^2 and 13.15N/mm^2 respectively. These corresponded to the mix ratio 1:1:2 at water cement ratio of 0.5. The 28 day strength values for LC were approximately half of those obtained at 90 days.

Compressive strength values obtained for 90 days lime concrete were close to those obtained for OPC concrete at 7 days. The strength values of the lime concrete were lesser than those of their controls. These strength values of the lime concrete were close to those obtained for OPC concrete at 7 days. The strength values of the lime concrete were far lesser than those of their controls. These values were also observed to increase with longer curing ages. The experimental values of the compressive strengths of the concrete are plotted against the selected mix ratios in Fig 3 and presented in the form of a bar chart in Fig 4.

Table 5: Compressive strength results for OPC concrete cubes and lime concrete cubes.

Mix no.	Mix ratio	W/c ratio	7 day OPC concrete strength (N/mm^2)	28 day OPC concrete strength (N/mm^2)	28 day lime concrete strength (N/mm^2)	90 day lime cement concrete strength (N/mm^2)
M1	1:3:6	0.60	11.55	18.22	2.35	4.40
M2	1:2:4	0.57	10.76	23.85	4.95	10.09
M3	1:2:5:5	0.55	9.30	25.33	5.73	11.50
M4	1:1:5:3	0.53	9.83	20.59	3.29	6.63
M5	1:1:2	0.50	10.23	26.90	6.12	13.15

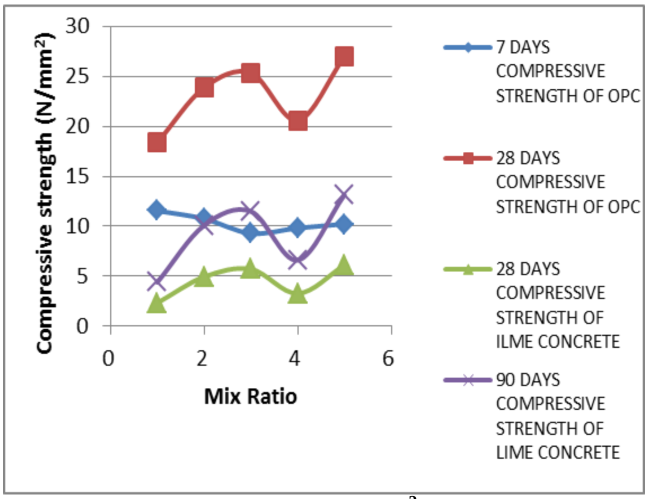

Fig 3: Compressive strength (N/mm^2) vs. mix ratios

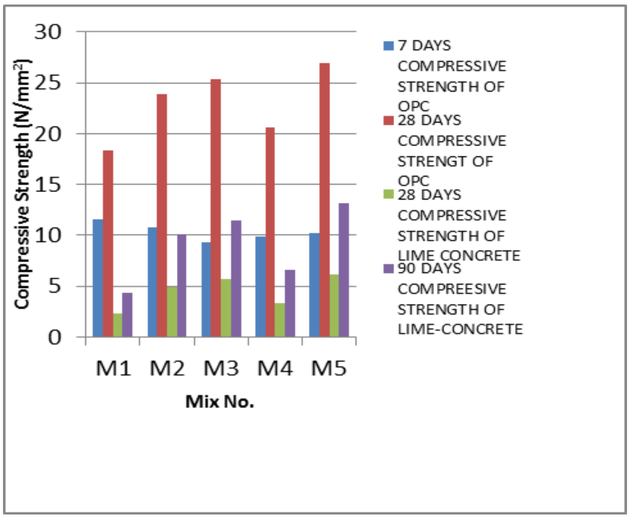

Fig 4: Bar chart of compressive strength (N/mm^2) vs. mix ratios.

5. Conclusion

i. Compressive strength values obtained at the 28th day for the lime concrete are approximately 50% of those obtained at 90 days.

ii. From the five mix ratios studied, it can be concluded that the optimum mix ratio for the OPC concrete and lime concrete is 1:1:2 at 0.5 water-cement ratio.

iii. Optimum value of compressive strength for OPC concrete at the 28th day is 26.90N/mm^2 while that for the lime concrete is 6.12N/mm^2. At 90 days, the value of the compressive strength of lime concrete increased to 13.15N/mm^2. These strengths occurred at mix no M5.

iv. Mix no. M4, which is a high quality mix by convention, recorded lower values of strength, when compared to other less strength mix ratios. This could be due to inadequate water-cement ratio resulting to incomplete hydration process.

vi. Compressive strength results at 90 days for lime concrete were close to the 7 days results for OPC concrete. No value of compressive strength at 7 days was observed for the LC.

vii. At early curing ages, lime concrete have very low strength. This strength increases as the curing age is prolonged.

6. Recommendation

i. The use of lime concrete for constrcuction purpose results to very low compressive strength of the concrete. Therefore, this concrete will require the addition of other pozzolanic materials to improve its strength properties, so as to harness its durabilty and environmental friendly benefits.

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