Flexural and Split Tensile Strength Properties of Lime Cement Concrete

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Abstract

This paper investigated the flexural strength and split tensile strength properties of hydrated lime cement concrete. Ordinary portland cement was partially replaced by hydrated lime at varying percentages ranging from 5% to 30%. Concrete under study was made of ordinary portland cement (OPC), hydrated lime, river sand, granite chippings and water. The test specimen were prototype concrete beams of sizes 150x150x600mm and concrete cylinders of dimensions 150x300mm. Three concrete specimens were cast for each mix ratio considered, and cured in open water tanks for 7, 14, 21, and 28 days for the beams, and cylinders respectively. Since there were 30 different mix proportions considered, a total of 360 concrete prototype beams, and 360 concrete cylinders were produced and cured before testing in tension. Maximum design strength recorded in flexure at 7, 14, 21 and 28 days were 3.08N/mm^2, 3.580N/mm^2, 4.910N/mm^2 and 5.03N/mm^2 respectively, while those recorded in splitting were 1.565N/mm^2, 2.350N/mm^2, 3.605N/mm^2, and 3.725N/mm^{2}respectively. It was observed that tensile strength values from the flexural test gave higher values than those of the split tensile test. Strength properties increased with curing age. Optimum replacement of OPC with hydrated at 28 days curing age was observed at 13.83% for both properties. Optimum mix ratio for the two properties studied was 0.863:0.138:2.625:5.250 at a water cement ratio of 0.58. Hydrated lime cement concrete can be used effectively for structural works at curing age of 28 days and beyond.

Keywords: Flexural strength, Split tensile strength, Hydrated lime, ordinary portland cement

1. Introduction

At the time during which concrete was first invented, ancient materials were crude cement made by crushing and burning gypsum or limestone. When sand and water were added to these cements, they became mortar which was used to join stones to each other. Over thousands of years, these materials were improved upon, combined with other materials and, ultimately into modern concrete (Nick and Kenton, 2014). In the beginning of the 20th century, there was usage of hydrated lime as an admixture in poured concrete (Mira et al, 2002). Lime was used as the basis for the pozzolanic material in concrete for thousands of years before the development of Portland cement in the late eighteenth century (Holland et al., 2012).The principal advantages for this admixture on the property of the concrete was improved water-tightness and impermeability.

The manufacture and use of concrete lead to a wide range of environment and social consequences. Cement which is a major component of concrete exerts similar environmental and social effects (Navdeep et al., 2012). Cement production is a significant source of global carbon dioxide (CO_2) emissions. This gas depletes the ozone layer, i.e. the "greenhouse effect" that has caused a lot of harm to the ecosystem by increasing the atmospheric temperature (Srinivasan et al., 2010). Most cement plants consume much energy and produce a large amount of undesirable products, which affect the environment (Ahmed et al., 2009). The need to tackle these challenges has resulted to the use of environmentally friendly and energy saving materials (e.g. hydrated lime) as partial replacement of ordinary Portland cement in concrete production.

The inclusion of hydrated lime as a partial replacement of OPC will assist in reducing the emission of the green-house gas CO_2 to the atmosphere. This is possible since a reduction in the amount of the clinker content in cement production by hydrated lime will reduce the amount of CO_2 released into the atmosphere during the calcination of the clinker (Afsah, 2004). Also, the addition of hydrated lime as a partial replacement of clinker will result to lower calcination temperature (800^0C – 1000^0C), thereby reducing CO_2 emissions from the fossil fuel used to heat up the cement kilns. This temperature is substantially lower than the 1450^0C which is needed for the calcination of limestone to produce portland cement (Yang, 2013). Hydrated lime in concrete has the ability of re-absorbing CO_2 gases from the atmosphere (Spano, 2009). Therefore, since, lime production leaves a smaller carbon footprint than OPC, the use of lime cement concrete will lead to a reduction of green-house gases to the atmosphere.

Concrete as known, is relatively strong in compression and weak in tension. In reinforced concrete members, little dependence is placed on the tensile strength of concrete since steel reinforcing bars, are provided to resist all tensile forces. However, tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons (Shetty, 2006). Hence, the knowledge of tensile strength of concrete is of importance. It has been argued that the flexural strength property of concrete is important particularly when the concrete structure has no steel reinforcement. For example, unreinforced concrete roads and runways rely on their flexural strengths to safely distribute concentrated loads over wide areas (Osadebe and Nwokonobi, 2007). This is true for the split tensile strength property of concrete. Therefore, findings from this research will have great significance in providing relevant data for the analysis and design of structures by consultants and practitioners in the construction industry.

2.0 Literature review

Jayaraman et al. (2012) carried out tensile test on concrete made using lateritic sand and limestone filler as fine aggregates. The laterite was varied from 0% to 100%, while the limestone filler was varied at intervals of 25%. They observed that at 0.55 water/cement ratio, the tensile strength ranged between 10.06N/mm^2 to 15.5 N/mm^2 for all the mixes they considered. The concrete was found to be suitable for structural works, where laterite content did not exceed 50%. Upata and Ephraim (2012) investigated on the flexural and tensile strength properties of concrete using lateritic soil and quarry dust as fine aggregates. Their results showed that flexural strengths were 3.28N/mm^2 for 50% laterite: 50% quarry dust and 2.88N/mm^2 for 25% laterite: 75% quarry dust. Similarly, tensile strengths were 2.91N/mm^2 for 50% laterite: 50% quarry dust and 1.67N/mm^2 for 25% laterite: 75% quarry dust. These indicated that both flexural and tensile strengths increase with increase in laterite content. The results suggested that concrete containing mixtures of lateritic sand and quarry dust can be reasonably used in structural elements as for normal concrete (concrete with river sand as fine aggregate).

Linora et al. (2015) worked on the investigations on optimum possibility of replacing cement partially by red mud in concrete. They reported that 15% of cement can be optimally replaced by red mud beyond which compressive strength, split tensile strength, and flexural strength starts to decrease. They also stated that cement replacement by red mud up to 15% yielded characteristic strengths greater than conventional concrete. Nova (2013) reported that the increase in metakaolin content improved the split tensile and flexural strength of the concrete up to 15% replacement.

Arivalang (2012), in his study on the split tensile strength properties of basalt fiber concrete member, discovered that the compressive strength and the split tensile strength of basalt fiber concrete specimen were higher than those for the control concrete specimen at all ages. Also, strength difference between basalt fiber concrete specimen and the control concrete specimen were high at the beginning age of curing. The concrete attained splitting tensile strength in the range of 123% - 125% at 28days when compared to the control at 28days.Wakchaure et al. (2012), conducted split tensile test on plain cement concrete with natural sand as fine aggregate and the other with artificial sand. They discovered that the tensile strength difference between the two concretes were marginal, the values being 3.78MPa for the natural sand concrete and 3.71MPa for artificial sand concrete. They also discovered that the split tensile strength for all specimen, were more than 10% of compressive strength of the concretes.

3.0. Materials and Methods

The materials and methods used for this study are as following:

3.1 Materials

Dangote cement, a brand of OPC, which conformed to the requirements of BS 12 (1978) was used for this study.The initial and final setting time was 60mins and 435mins respectively. Hydrated lime conforming to ASTM C207 standard was purchased from Dugbe, in Ibadan, Oyo state. Chemical property tests on the OPC and hydrated lime were carried out. Locally available river sand from Otamiri, river was used as the fine aggregate. The sand was poorly graded and fell under zone 1 i.e. it was a coarse sand (IS 383:1970). Granite chippings of maximum size 19mm (obtained from Setraco quarry site at Uturu in Abia State) was used as the coarse aggregate.It was poorly graded and contained uniform range of particle sizes. Water for this study was potable in nature.

3.2 Methods

Two different types of concrete specimen were produced in the laboratory. These included; 150mm x 150mm x 600mm concrete prototype beam specimen prescribed according to BS 1881-118 (1983) and 150mm x 300mm cylindrical concrete specimen prescribed according to BS EN 12390-6:2009.

(a) Mix design

The concrete under study was a five component mixture; therefore, five starting set of mix ratios (N1 to N5) were used to generate extra twenty five mix ratios using the Henry Scheffes simplex lattice (Anyanwu, 2011). This gave a total of thirty mix ratios. Batching of the components of the concrete was by weight and mixing was done manually on a smooth concrete pavement. Required proportion of OPC and hydrated lime were 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.

(b) Casting and testing

The test specimen were the prototype concrete beams and concrete cylinders. Three concrete specimens were cast for each mix ratio considered, and cured in open water tanks for 7, 14, 21, and 28 days for the beams, and cylinders respectively. Since there were 30 different mix proportions, a total of 360 concrete prototype beams, and 360 concrete cylinders were produced and cured before testing in tension (i.e. in flexure, and splitting respectively).

The flexural strength test was performed according to BS 1881-118 (1983).The load under which the specimen failed was recorded and used to obtain the flexural strength of the concrete using the formula in equation (2.1). The third point loading method of flexural testing of concrete beams was adopted.

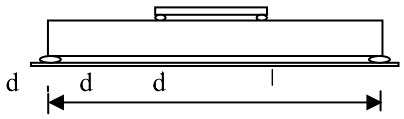

Fig 1: Principle of the third point loading method of flexural testing of concrete beams

Flexural strength (MOR) = PL/bd^2 (2.1)

where; MOR = modulus of rupture (N/mm^2), P = maximum applied load indicated by the testing machine (N), L = span length (mm), b = average width of specimen (mm) and d = average depth of specimen (mm).

The cylindrical splitting tension test was conducted using the universal testing machine according to BS EN 12390-6:2009. The load was applied against the specimen along its center line. This load was then gradually increased until failure occurred by splitting. The horizontal tensile stress was calculated as given in equation (2.2).

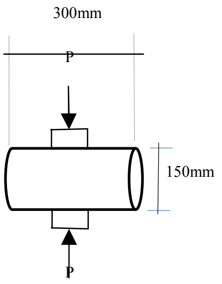

Fig 2: Concrete cylinder specimen used for split tensile testing

$O_{sp} = 2P/\Pi dl$ (2.2)

Where, P = maximum applied load; d = diameter of the cylindrical specimen; and l = length of the specimen.

4.0 . Results and Discussion

4.1 Results

The results of the chemical property test conducted on the ordinary Portland cement and hydrated lime are presented in Table 1 while the results of the flexural strength test and split tensile strength on the lime cement concrete are presented on Table 2 and Table 3 respectively.

Table 1. Chemical properties of ordinary portland cement (OPC) and hydrated lime

S/NO	**Chemical properties**	**Content in mass fraction for OPC**	**% Composition of hydrated lime**
1	Calcium Oxide (CaO)	67.62	93.0
2	Moisture (H_2O)	0.003	0.58
3	Silicon Oxide(SiO_2)	20.39	2.38
4	Aluminum Oxide(AL_2O_3)	6.03	2.04
5	Iron Oxide	2.29	-
6	Magnesium Oxide(MgO)	1.31	2.0
7	Potassium oxide (K_2O)	0.54	-
8	Titanium oxide (TiO_2)	0.20	-
9	Loss on ignition	2.80	-
7	pH	9.2	8.6

Table 2: Flexural strength results for the lime cement concrete

S/No	Mix No.	Ordinary portland cement	Hydrated lime	Sand	Granite chippings	Water cement ratio	Flexural Strength (N/mm^2)			
							7th day results	14th day results	21st day results	28th day results
1	N1	0.900	0.100	3.000	6.000	0.6000	1.480	1.720	2.160	2.280
2	N2	0.850	0.150	2.000	4.000	0.5700	1.750	2.350	3.560	3.860
3	N3	0.800	0.200	2.500	5.000	0.5500	1.630	2.160	3.390	3.620
4	N4	0.700	0.300	1.500	3.000	0.5300	1.600	3.000	3.330	3.490
5	N5	0.600	0.400	1.000	2.000	0.5000	1.740	1.950	2.630	2.960
6	N12	0.875	0.125	2.500	5.000	0.5850	2.300	2.860	4.200	4.370
7	N13	0.850	0.150	2.750	5.500	0.5750	2.450	2.840	3.410	3.910
8	N14	0.800	0.200	2.250	4.500	0.5650	1.930	2.650	3.420	3.980
9	N15	0.750	0.250	2.000	4.000	0.5500	1.820	2.220	3.020	3.230
10	N23	0.825	0.175	2.250	4.500	0.5600	1.650	2.890	4.270	4.390
11	N24	0.775	0.225	1.750	3.500	0.5500	2.250	2.780	4.080	4.260
12	N25	0.725	0.275	1.500	3.000	0.5350	2.170	2.540	3.400	3.580
13	N34	0.750	0.250	2.000	4.000	0.5400	1.620	1.800	2.600	2.770
14	N35	0.700	0.300	1.750	3.500	0.5250	1.470	1.630	2.890	2.940
15	N45	0.650	0.350	1.250	2.500	0.5150	1.580	1.680	2.520	2.670
16	C1	0.875	0.125	2.550	5.000	0.5860	2.430	2.960	4.380	4.510
17	C2	0.850	0.150	2.750	5.550	0.5750	2.250	2.560	3.040	3.270
18	C3	0.775	0.225	1.750	3.550	0.5500	2.140	3.580	3.840	4.020
19	C4	0.700	0.300	1.750	3.550	0.5250	1.400	1.660	2.360	2.820
20	C5	0.650	0.350	1.250	2.500	0.5170	1.510	1.740	2.700	2.700
21	C6	0.863	0.138	2.625	5.250	0.5800	2.220	3.510	4.910	5.030
22	C7	0.763	0.238	1.875	3.750	0.5500	3.080	3.330	3.730	3.850
23	C8	0.813	0.187	2.250	4.500	0.5625	1.640	2.990	4.200	4.360
24	C9	0.732	0.268	1.825	3.650	0.5429	2.320	2.670	3.480	3.670
25	C10	0.799	0.201	2.325	4.330	0.5597	1.670	3.120	4.060	4.150
26-	C11	0.817	0.183	2.163	4.330	0.5667	2.030	3.250	4.120	4.280
27	C12	0.790	0.210	2.150	4.300	0.5570	1.960	3.260	3.900	4.100
28	C13	0.775	0.225	2.100	4.200	0.5530	2.270	2.630	2.930	3.020
29	C14	0.813	0.188	2.225	4.450	0.5620	1.640	3.100	4.460	4.520
30	C15	0.790	0.210	2.100	4.200	0.5600	1.830	3.160	4.020	4.160

Table 3: Summary of Split tensile strength results for the lime cement concrete

S/No	Mix No.	Ordinary portland cement	Hydrated lime	Sand	Granite chippings	Water cement ratio	Split tensile strength (N/mm^2)			
							7th day results	14th day results	21st day results	28th day results
1	N1	0.900	0.100	3.000	6.000	0.6000	1.300	1.540	1.980	2.100
2	N2	0.850	0.150	2.000	4.000	0.5700	0.800	1.400	2.605	2.905
3	N3	0.800	0.200	2.500	5.000	0.5500	0.710	1.240	2.470	2.700
4	N4	0.700	0.300	1.500	3.000	0.5300	0.690	2.095	2.425	2.585
5	N5	0.600	0.400	1.000	2.000	0.5000	1.130	1.340	2.020	2.250
6	N12	0.875	0.125	2.500	5.000	0.5850	1.360	1.770	3.110	3.280
7	N13	0.850	0.150	2.750	5.500	0.5750	1.225	1.785	2.335	2.835
8	N14	0.800	0.200	2.250	4.500	0.5650	0.490	1.210	2.350	2.540
9	N15	0.750	0.250	2.000	4.000	0.5500	1.015	1.415	2.215	2.425
10	N23	0.825	0.175	2.250	4.500	0.5600	0.610	1.850	3.230	3.350
11	N24	0.775	0.225	1.750	3.500	0.5500	1.190	1.720	3.020	3.200
12	N25	0.725	0.275	1.500	3.000	0.5350	1.240	1.610	2.470	2.650
13	N34	0.750	0.250	2.000	4.000	0.5400	0.930	1.110	1.910	2.080
14	N35	0.700	0.300	1.750	3.500	0.5250	0.735	0.895	2.155	2.205
15	N45	0.650	0.350	1.250	2.500	0.5150	0.910	1.010	1.850	2.000
16	C1	0.875	0.125	2.550	5.000	0.5860	1.300	1.830	3.250	3.380
17	C2	0.850	0.150	2.750	5.550	0.5750	1.430	1.740	2.220	2.450
18	C3	0.775	0.225	1.750	3.550	0.5500	1.135	1.575	2.835	3.015
19	C4	0.700	0.300	1.750	3.550	0.5250	0.700	0.820	2.050	2.115
20	C5	0.650	0.350	1.250	2.500	0.5170	0.835	1.065	1.875	2.025
21	C6	0.863	0.138	2.625	5.250	0.5800	0.915	2.205	3.605	3.725
22	C7	0.763	0.238	1.875	3.750	0.5500	1.565	2.350	2.720	2.850
23	C8	0.813	0.187	2.250	4.500	0.5625	0.550	1.900	3.110	3.270
24	C9	0.732	0.268	1.825	3.650	0.5429	1.400	1.750	2.560	2.750
25	C10	0.799	0.201	2.325	4.330	0.5597	0.630	2.080	3.025	3.115
26	C11	0.817	0.183	2.163	4.330	0.5667	0.960	2.180	3.050	3.210
27	C12	0.790	0.210	2.150	4.300	0.5570	0.940	2.235	2.875	3.075
28	C13	0.775	0.225	2.100	4.200	0.5530	1.500	1.860	2.160	2.250
29	C14	0.813	0.188	2.225	4.450	0.5620	0.520	1.980	3.340	3.400
30	C15	0.790	0.210	2.100	4.200	0.5600	0.770	2.150	2.950	3.120

A plot of the flexural strength against mix proportions, and split tensile strength against mix proportions are presented in Fig 3 and Fig 4 respectively..

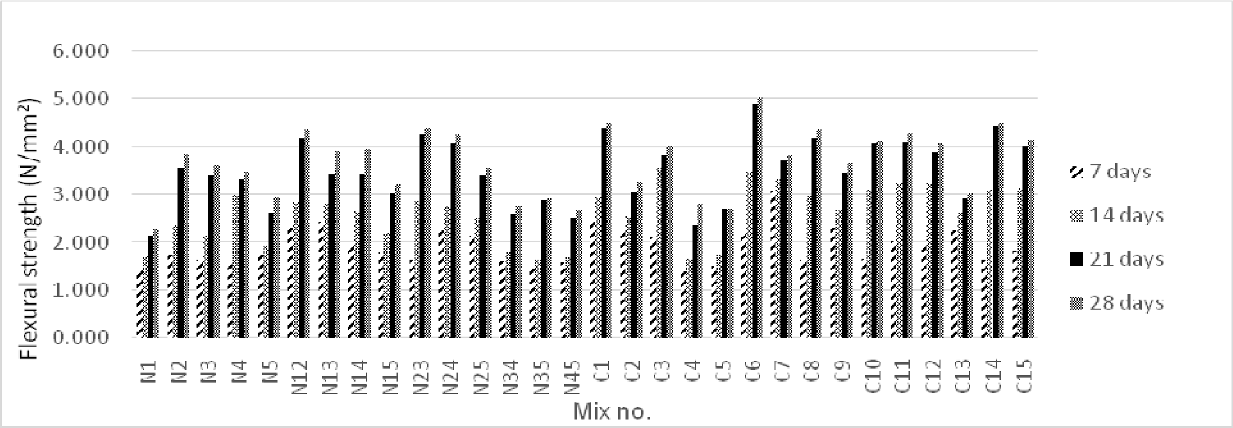

Figure 3. Flexural strength vs. mix proportions.

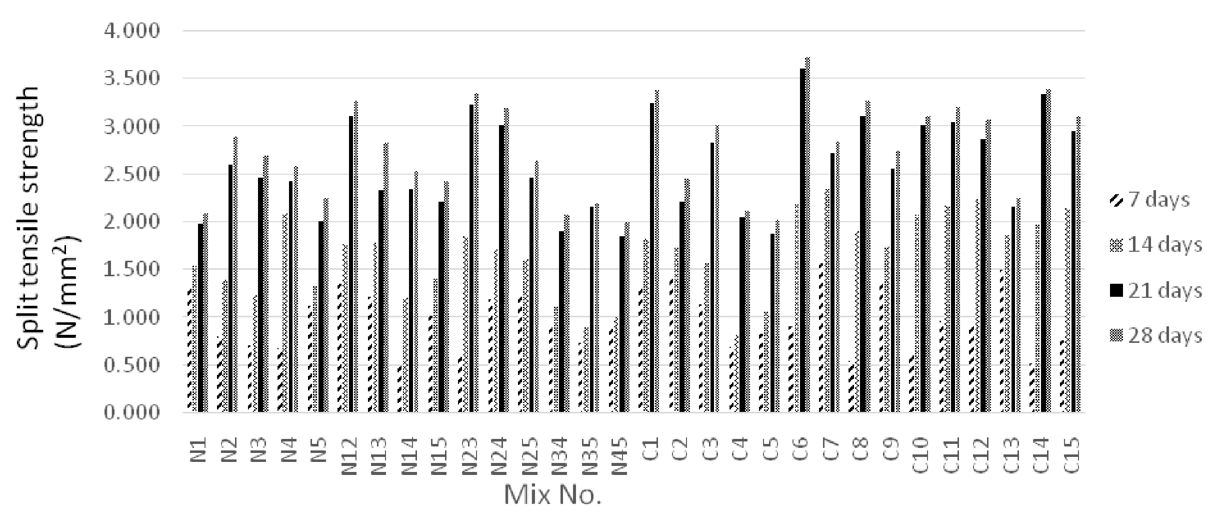

Figure 4. Split tensile strength vs. mix proportions.

4.2 Discussion

From Table 2, Optimum replacement of OPC with hydrated at 28 days curing age was observed at 13.83% for the flexural strength test and the split tensile test respectively. This occurred at an optimal mix of 0.863:0.138:2.625:5.250. The highest flexural strength values obtained at 7 days, 14 days, 21 days and 28 days of curing were 2.45N/mm^2, 3.51N/mm^2, 4.91N/mm^2 and 5.03N/mm^2 respectively. These strength values corresponded to mix label N13 for the 7 days strength, and C6 for the 14 days, 21 days, and 28 days strength respectively at a water cement ratio of 0.55.

Similarly, the highest split tensile strength values obtained at 7, 14, 21 and 28 days of curing were 1.50N/mm^2, 2.235N/mm^2, 3.605N/mm^2 and 3.725N/mm^2 respectively. These strength values corresponded to mix label C13 for the 7 days strength, and C12 for the 14 days strength, and C6 for the 21 days, and 28 days strength respectively.

5.0. Conclusion

The strength of hydrated lime-OPC composite varies with both percentage replacement of OPC with hydrated lime and water cement ratio. Optimum replacement of OPC with hydrated lime was recorded at 13.83% for 28 days of curing. Maximum strengths recorded were 5.03N/mm^2 for flexural strength and 3.725N/mm^2 for split tensile strength. It was observed that the strength values in flexure were higher than those in split tensile. Optimum mix ratio for the two properties studied was 0.863:0.138:2.625:5.250 at a water cement ratio of 0.58.

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