Performance studies on limestone calcined clay based concrete

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Abstract: In the construction field, lot of improvement in sustainable development is going on from last few decades, mainly use of pozzolanic materials are increasing day by day for the production of cement. On the other hand a lot of anthropogenic CO₂ gas is liberating in to atmosphere while manufacturing cement. To alter the emission of CO₂ use of alternative cementious materials is one of the best practices like fly ash, rice husk ash, GGBS and Metakaolin. Due to the use of such materials there is a lag in early strength development in concrete. Hence there is need to develop a substitute material for cement without negotiating in properties. In the present paper Limestone Calcined Clay Cement (LC₃) as an alternative to Ordinary Portland Cement (OPC) is examined for strength and durability and the results are compared with Portland Pozzolana Cement (PPC) for M 50 grade of concrete. From results it is found that the use of LC₃ concrete is beneficial in terms of strength and durability.

Keywords: Calcined clay; Limestone; Compressive Strength; RCPT; Sustainability.

1. INTRODUCTION

In the present days context, for the production of concrete requires large quantity of resources and energy consumption is also more for manufacturing cement, which is also a pollution intensive material. Due to this, cement industry is facing lot of problems like: (i) Anthropogenic CO₂ gas is liberating to atmosphere. (ii) More quantity of fuel is required for clinkering process. (iii) Degradation of natural materials and (iv) Cost of manufacturing is increased per unit [1, 2]. To address these problems, somehow benefit of blending Portland Pozzolana Cement (PPC) for reduction of the carbon emissions and fuel energy capacity is up to a certain amount only. More quantity of CO₂ emissions can be reduced by making alternative cements through blending highly reactive pozzolana materials [3, 4]. Utilization of secondary cementitious materials (SCM’s) for making concrete is increased to improve the quality and durability of concrete structures, in line to that a new LC₃ concrete can achieve desired properties without compromising the quality [5, 6]. LC₃ is treated at low level temperatures of about 800°C-900°C when compared to cement for the activation of pozzolanic action, further it changes to metakaolin which is...
highly reactive pozzolana [7]. The pozzolana activity for calcined clay is materializing mainly due to the formation of metakaolin while treating clay minerals. Further metakaolin reacts as pozzolanic material with calcium hydroxide, water and sulphate to form calcium alumina silicate hydrate and alumina ferrite phases [8, 9]. For achieving sufficient workability and early age strength there is no need of high purity of kaolinite. In clay deposits, about 40% of kaolinite content can perform well by making some changes in the distribution of particles of cement compounds [10, 11]. The main idea of combining limestone with calcined clay is, limestone helps to promote the hydration of clinker by facilitating suitable surface area for nucleation of hydrates and responsible for hydration reactions in the presence of aluminates. The quantity of limestone reacted phases depends on the purity of aluminate sources, presence high kaolinite content responsible for the development of strength in LC$_3$ concrete [12, 13]. Present study focused to examine the performance of LC$_3$ based concrete in terms of mechanical strength and durability.

2. IMPORTANCE OF THE STUDY

Several investigators has concentrated on developing alternative materials for cement. Due to the increase of cement utilization there is an urgency to alter cementitious materials without compromising the strength and durability, which can be achieved by combining two or more cementitious materials. Few of authors had investigated on blended cements like limestone calcined clay cement which can be future cementitious material in the sustainable point of view. It is a basic thing to find out the characteristics of such type of binder while it is being mixed with several ingredients like fine aggregate, coarse aggregates and water. Present investigation is focused to know the efficiency of limestone calcined clay concrete by conducting tests on M 50 grade of concrete and the values of LC$_3$ specimens are compared with OPC and PPC based concrete specimens.

3. METHODOLOGY AND EXPERIMENTS

Present study is carried out to investigate the performance of LC$_3$ based concrete and compared with OPC and PPC based concretes. In the present paper M 50 grade of concrete is considered and designed according to IS 10262-2019. The details of proportions of mix are shown in Table 1. The parameters in the study include grade of concrete (M$_{50}$), Type of binder (LC$_3$, OPC and PPC) and age of curing (i.e. 7, 14 and 28 days). To determine the strength properties, compressive, split tensile and flexural strength tests are carried out on specimens and the durability studies are Rapid chloride ion penetration test and absorption and desorption tests. The specimens were designated according to the grade of concrete, type of concrete. Typically a concrete specimen labeled Mix AO represents M 50 grade concrete containing OPC, Mix AP represents M 50 grade concrete containing PPC and Mix AL represents M 50 grade concrete with 0.34 w/c ratio, containing Limestone calcined clay cement.

Table 1- Mix proportions for M 50 grade concrete
### Materials

| Materials                         | Quantities (kg/m³) |
|----------------------------------|--------------------|
| Binder (OPC, PPC and LC₃)        | 450                |
| Fine aggregate                   | 627                |
| Coarse aggregate                 | 1212               |
| Water                            | 153                |
| Super plasticizer                | 7                  |

#### 3.1 Materials used:

1. Ordinary Portland Cement (OPC): 53 grade OPC conforming to IS 12269-2013 is used in present study and its physical properties are given in Table 2.
2. Portland Pozzolana Cement (PPC): PPC conforming to IS 1489-1 (1991) is used for investigation and the properties are shown in Table 2.
3. Limestone Calcined Clay Cement (LC₃): It is procured from society for Technology and Action for Rural development Authority, New Delhi, India. Table 2 shows the physical properties of LC₃.
4. Fine aggregate (FA) and Coarse aggregate (CA): As per IS: 383-2016 codal provisions fine and coarse aggregate were used. The properties are shown in Table 3.
5. Super Plasticizer: Poly carboxylic ether based water-reducing admixture confirming ASTM C494 [20] is used as super plasticizer for better workability.

### Table 2 Properties of OPC, PPC and LC₃

| S.NO | PROPERTY               | OPC     | PPC     | LC₃     |
|------|------------------------|---------|---------|---------|
| 1    | Normal consistency     | 31 %    | 32 %    | 33 %    |
| 2    | Initial setting time   | 33 minutes | 32 minutes | 35 minutes |
| 3    | Final setting time     | 460 minutes | 480 minutes | 270 minutes |
| 4    | Specific gravity       | 3.11    | 2.98    | 2.79    |
| 5    | Fineness               | 4%      | 7%      | 6%      |
| 6    | Compressive strength in MPa | 54.1 | 50.2    | 53.5    |

### Table 3: General properties of CA and FA

| Properties          | CA | FA |
|---------------------|----|----|
| Bulk Density (g/cc) | 1.62 | 1.71 |
| Specific gravity    | 2.78 | 2.57 |
| Fineness modulus    | 7.44 | 2.67 |
| Void ratio          | 1.01 | 0.92 |
| Porosity            | 41% | 49% |
3.2 Experiments:

(a) Compressive Strength Test (CST): The cube of size 150×150×150 mm is considered and as per IS 516 (1959) [14] test is conducted on 3000 kN compression testing machine.

(b) Split Tensile Strength Test (STST): The test is carried out on the cylinder of 150 mm dia. and 300 mm height as per IS 5816-1999 [15].

(c) Flexural Strength Test (FST): The prism of size 500×100×100 mm is used to determine the flexural strength of concrete specimens and as per IS 516 codal provisions, the test is carried out on specimens.

(d) Rapid Chloride ion Penetration Test (RCPT): This test is performed according to ASTM C 1202-97 [16]. Specimen of 50 mm thick and 100 mm dia. is considered for testing. The charge passed (Total) is found out and is used to rate the quality of the concrete according to ASTM C 1202 rating.

(e) Absorption Test (AT): The absorption test is used to measure the rate of absorption of water by the concrete specimen by finding the increase in the mass of a specimen with function of time when cubes are immersed in water for a period of 72 hrs.

(f) Desorption Test (DT): This test is done to know the rate of evaporation of water in the concrete by finding the decrease in the mass of a specimen with function of time when cubes are kept in hot air oven for 72 hours at 105°C. The cubes which are cured upto 28 days are taken from curing tank and surface dried before they are kept in hot air oven.

4. RESULTS AND DISCUSSIONS

4.1 Compression Test:

Figure 1 shows the results for compressive strength for M 50 grade concrete with different types of binders. From 28 days results it is clearly observed that the mixes attain the target strength. Based on the 7 days results it is evident that the LC₃ concrete has shown better performance in terms of early strength gain when compared to PPC concrete. By seeing the 28 days test results it is evident that LC₃ specimens performed better than that of other binder concretes. The enhancement of strength is mainly due the formation of dense and compact micro structure of LC₃ particles. On the other hand PPC based concrete is shown less strength compared to OPC and LC₃. Reason for achieving better strength values is mainly due to the dense uniform morphology of LC₃ and a large quantity of alumina is available in calcined clay which will react
with calcium carbonate present in limestone to produce alumina phases. On the other hand PPC is a binary system and LC3 is ternary system, while comparing both it is found that the early strength gain during first 7 days is more in LC$_3$ concrete which resolves the problem of low strength gain at early ages.

![Figure 1 Compressive strength results for M 50 grade concrete with different binders](image1)

**4.2 Split Tension Test:**

Figure 2 shows the split tensile strength results for mixes A with different types of binders. From STST results it is noticed that, similar values are obtained for all types of concrete irrespective of type of binder. All the STST values are on par with marginal differences only, the effect of pozzolana activity is not much but LC$_3$ concrete specimens attained strength more than that of OPC and PPC based concrete specimens.

![Figure 2 Split Tension Test results](image2)
Figure 2 Split Tensile strength Test results for M 50 grade concrete with different binders

4.3 Flexural Strength Test:
Figure 3 shows the result for flexural strength for mixes A with different binders. It is clearly observed that the performance of LC3 concrete is better when compared with OPC and PPC based concretes. An average of 12 percentage of increase in flexural strength is observed.

![Figure 3 Flexural Strength Test results for M 50 grade concrete with different binders](image)

Table 4: RCPT Results for M50 grade of concrete with different binders

| S. No. | Mixes | Charge passed (Coulombs) | Chloride ion permeability as per ASTM C 1202 |
|--------|-------|--------------------------|---------------------------------------------|
| 1      | AO    | 1011                     | low                                         |
| 2      | AP    | 897                      | Very low                                   |

4.4 RCPT Results:
Table 4 shows the RCPT results for M 50 grade concrete with different types of binders. From the values of charge passed through specimen it is evident that the ingress of chloride ions into LC3 concrete specimens is less compared to other specimens. From this it is clear that the strength properties are enhanced with the RCPT results. LC3 concrete specimens are less vulnerable to chloride ingress, which is due to the refinement of pore sizes and having low pore threshold radius value. Due to the presence of fibrillar-like core structure LC3 based concrete helps in strengthening the concrete structures form environmental effects like chloride attack and carbonation.
4.5 Absorption and Desorption Test Results:

Table 5 shows the absorption for M50 grade of concrete with different binders. From table 4 it is observed that the rate of absorption all specimens is linear up to 6 hours than the curve is almost straight for all specimens irrespective of type of binder and grade of concrete. On other hand it is clear that LC3 concrete specimen shown lesser water absorption when compared to OPC and PPC based concrete specimens. As pore inter connection is less in LC3 concrete and the inter layer space between the calcium ions and silicate chains is filled with water and calcium ions. The rate water absorption is less in case of LC3 concrete; whereas in OPC based concrete specimens the rate water absorption is more due to less dense microstructure and inter connectivity of pores is more as compared to PPC based concrete.

Table 5 Percentage of water Absorption for M 50 grade concrete with different binders

| Time (hours) | Water Absorption (%) |
|--------------|-----------------------|
|   | AO | AP | AL |
| 0  | 0  | 0  | 0  |
| 0.5| 1.445 | 1.353 | 0.998 |
| 1.5| 2.088 | 1.91 | 1.397 |
| 3  | 2.489 | 2.229 | 1.756 |
| 5  | 3.052 | 2.667 | 2.235 |
| 6  | 3.253 | 2.786 | 2.355 |
| 8  | 3.413 | 2.945 | 2.514 |
| 10 | 3.694 | 3.184 | 2.794 |
| 12 | 3.895 | 3.383 | 2.914 |
| 24 | 4.037 | 3.702 | 3.353 |
| 30 | 4.037 | 3.742 | 3.353 |
| 36 | 4.037 | 3.742 | 3.353 |
| 48 | 4.037 | 3.861 | 3.512 |
| 60 | 4.057 | 3.861 | 3.512 |
| 72 | 4.128 | 3.901 | 3.512 |
4.6 Desorption Test Results:

Table 6 shows the percentages of water desorption for M 50 grade concrete with different binders. From the values of desorption it is found that the loss of water is more in initial hours i.e. up to 24 hours and then the curve is almost straight. At a temperature of 105° C freely available water molecules are evaporated in concrete specimens. These voids present in the concrete are responsible for the ingress of harmful chemicals into concrete. Concrete with less percentage water desorption is more durable than that of other concrete specimens. From curves it is found that the LC3 concrete specimens prone to less desorption compared to OPC and PPC concrete specimens. It is evident that the LC3 concrete has dense microstructure and compact core structure which does not allow the water desorption and this is due to the presence of finer particles in LC3 concrete and more reactivity pozzolana action is taken place which in turn requires more amount of water to form secondary gel phase. There is a clear coincidence in durability and strength results, which helps to strengthen the performance of LC3 concrete in all aspects. Ternary blended concretes are more durable than that of OPC due to the effect of fine grain particles and compact core structure of concrete. Enhanced properties of LC3 concrete is mainly due to the high reactivity pozzolana action which fills the space and contribute to the better performance in terms strength and durability.

Table 6 Percentage of water desorption for M 50 grade of concrete with different binders

| Time (hours) | Water Desorption (%) |
|--------------|-----------------------|
|              | AO        | AP        | AL        |
| 0            | 0         | 0         | 0         |
| 1            | 0.269     | 0.154     | 0.153     |
| 3            | 0.732     | 0.54      | 0.344     |
| 6            | 1.425     | 0.965     | 0.575     |
| 12           | 2.003     | 1.389     | 1.264     |
| 24           | 2.851     | 2.239     | 2.108     |
| 36           | 3.352     | 2.702     | 2.529     |
| 48           | 3.815     | 3.104     | 2.973     |
| 60           | 3.93      | 3.411     | 3.127     |
| 72           | 4.046     | 3.679     | 3.243     |
5. CONCLUSIONS

Based on the strength and durability tests on the use of LC3 in concrete and comparison with OPC and PPC based concretes, the following are the findings.

- Based on the strength properties, LC3 concrete performed better in terms of compressive strength and flexural strength.
- From RCPT results it is observed that the LC3 concrete cubes are subjected to low ingress of chloride ions compared to OPC and PPC concrete cubes.
- By water absorption and desorption test results it is evident that the limestone calcined clay concrete cubes resulted to low percentage of water absorption and desorption compared to other concrete cubes. Due to the fewer pores interconnection between the particles and the forming fibril structure morphology helps to decrease the ingress of harmful agents into the concrete further enhances the durability.
- From overall studies, it is concluded that the LC3 concrete specimens shown enhanced performance than that of concrete made with OPC and PPC.

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