Experimental studies on mechanical and durability characteristics of lc₃ concrete

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Abstract: In the present day context utilization of natural resources is increasing day by day, which is a burden for future generations. Limiting the usage of natural raw materials and development of sustainable methodologies is needed in all aspects of construction activities. In this regard, manufacturing of cement requires large amount of limestone deposits, fuel energy and on the other hand cement manufacturing liberates carbon dioxide (CO₂) into atmosphere. Liberation of CO₂ results in global warming which leads to climatic changes. Hence there is a need to develop an alternative material superior to cement without compromising its properties. To address the above problem present study is focused on examining the usage of Limestone Calcined Clay Cement (LC₃) as partial replacement to clinker to an extent of 50% in concretes. M 30 grade of concrete is considered for investigation with three types of binders (i.e. LC₃, Ordinary Portland Cement (OPC) and Pozzolana Portland Cement (PPC). From the studies on strength and durability it is evident that the performance of LC₃ concrete is better than OPC and PPC based concrete.

Keywords: LC₃; Strength; Durability; Absorption; Desorption; RCPT

1. INTRODUCTION

Now a day’s adapting to sustainable development is a challenging task i.e. without compromising the quality and durability of structural elements. By manufacturing of cement a lot of CO₂ is released to atmosphere which is responsible for green house gases, as cement is manufactured from local available materials and industrial bye products like fly ash slag etc. [1]. Benefit of blending Portland Pozzolana Cement (PPC) for reduction of the carbon emissions and fuel energy capacity is upto to certain amount only. More quantity of CO₂ emissions can be reduced by making alternative cements through blending highly reactive pozzolana materials like calcined clay with the combination of limestone [2, 3]. Utilization
of secondary cementious materials (SCM’s) for making concrete is increased to enhance the quality of concrete structures, in line to that by using of LC3 concrete can achieve desired properties without compromising the quality [4, 5]. LC3 is treated at low level temperatures 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 [6, 7]. The pozzolana activity for calcined clay is materializing mainly due to the formation of metakaolin while treating clay minerals. Further it 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 particle size of cement compounds [10, 11]. The main idea of combining limestone with calcined clay is, limestone helps to promote the clinker hydration, facilitates nucleation of hydrates by providing surface area and responsible for hydration reactions in the presence of aluminates. The quantity of limestone reacted depends on the purity of aluminate sources, presence high kaolinite content responsible for the development of strength in LC3 concrete [12, 13]. By replacement of clinker with LC3-50% has shown similar properties as that of OPC. Present study focused to examine the performance of LC3 based concrete in terms of mechanical and durability characteristics and to compare the results with OPC and PPC based concretes.

2. IMPORTANCE OF THE STUDY

Due to the increase of cement demand there is a need to alter cementious materials without compromising the properties. This can be achieved by blending clinkers into binary and ternary binders with the locally available materials. Several authors had investigated on such type blended cements like limestone calcined clay cement which can be future cementitious material from the sustainable point of view. It is necessitated to find out the characteristics of binder while it is being mixed with several ingredients like fine aggregate, coarse aggregates and water. Present study is focused to know the potential of LC3 concrete by conducting experiments on M 30 grade concrete and the results of LC3 concrete are compared with OPC and PPC based concretes.

3.0 MATERIALS AND EXPERIMENTS

Present study consisted of standard grade concrete (M 30), designed according to IS 10262-2019. The details of mix proportions for M 30 is (1:1.42:2.73:0.46) with 0.25% of super plasticizer is used by weight of cement (Ploy carboxylates either based) to maintain slump at 80-100 mm. The variables in the
study includes type of binder (LC3, OPC and PPC) and age of curing (i.e. 7, 28 days) for determining the mechanical properties. Compressive strength, Split tensile strength and Flexural strength tests are conducted and for durability performance, Rapid chloride ion penetration test, Absorption and Desorption tests were conducted on concrete specimens after 28 days curing. Typically a concrete specimen labelled Mix MO represents M 30 grade of concrete with 0.46 w/c containing OPC, Mix MP represents M 30 grade of concrete with 0.46 w/c containing PPC and Mix ML represents M 30 grade of concrete with 0.46 w/c ratio containing Limestone Calcined Clay Cement.

3.1 Materials used:
53 grade cement as per IS 12269-2013 is used in present study and the physical characteristics are given in Table 1. PPC conforming to IS 1489-1 (1991) is used for investigation and the properties are shown in Table 1. LC3 procured from society for Technology and Action for Rural development Authority, New Delhi, India is considered for investigation and the physical properties of LC3 are given in Table 1. Fine aggregate (FA) of size less 4.36 mm and conforming to zone-II as per IS: 383-2016 is used and Coarse aggregate (CA) consisted of two sizes (20mm and 10mm) mixed in the ratio of 60:40 is used to obtain well graded aggregate as per codal provisions IS: 383-2016. Physical Properties of FA and CA are given in Table 2.

Table 1: Physical characteristics of OPC, PPC and LC3

| S. No. | Property               | OPC  | PPC  | LC3  |
|--------|------------------------|------|------|------|
| 1      | Normal consistency     | 30%  | 31%  | 32%  |
| 2      | Initial setting time (minutes) | 73   | 83   | 65   |
| 3      | Final setting time (minutes) | 230  | 295  | 185  |
| 4      | Specific gravity       | 3.11 | 2.89 | 2.99 |
| 5      | Fineness               | 4%   | 8%   | 5%   |
| 6      | Compressive strength (MPa) | 54.6 | 49.2 | 53.5 |

Table 2: General properties of CA and FA

| S. No. | Property               | CA     | FA  |
|--------|------------------------|--------|-----|
| 1      | Bulk Density (g/cc)    | 1.64   | 1.73|
| 2      | Specific Gravity       | 2.65   | 2.57|
| 3      | Fineness Modulus       | 7.32   | 2.73|
| 4      | Void ratio             | 1.01   | 0.92|
| 5      | Porosity               | 36%    | 41% |
3.2 Experiments conducted:
For determining the mechanical characteristics of concrete specimens the following tests are conducted,
i) Compressive Strength Test (CST) is carried on cube specimen of size 150×150×150 mm and as per IS 516-1959 [13] test is conducted on 3000 kN Compression testing machine. ii) Split Tensile Strength Test (STST) as per IS 5816-1999 [14] is conducted on the cylinder specimen of size 150 mm dia. and 300 mm height and iii) Flexural Strength Test (FST) is conducted on prism of size 500×100×100 mm by two point loading system as per IS codal provisions. To determine the performance of LC3 following tests are considered: i) Rapid Chloride ion Penetration Test (RCPT) is performed according to ASTM C 1202-97 [15] on specimen of 50 mm thick and 100 mm diameter ii) Absorption Test (AT) is used to measure the rate of absorption of water by the concrete by finding the increase in the mass of a specimen as a function of time when cubes are immersed in water for a period of 72 hr. iii) Desorption Test (DT) is done to know the rate of evaporation of water in the concrete by finding the decrease in the mass of a specimen as a function of time when cubes are kept in hot air oven for 72 hours at 105°C. The percentage weight gain and weight loss of specimens is recorded for further analysis of results.

4. RESULTS AND DISCUSSIONS

4.1 Compressive Strength Test:
Compressive strength test results of M 30 grade concrete with different type binders is presented in Figure 1. It is found that the mixes attain the required strength after curing for 28 days. From the 7, 14 and 28 days results it is evident that the LC3 concrete had performed better than that of OPC and PPC based concretes. The improvement of strength in LC3 concrete is mainly due the uniform microstructure and dense morphology in inner core structure. Reason for achieving better strength values is due to the formation of more quantity of alumina in reactive product and the presence of calcium carbonate in limestone allows producing carbon aluminate hydrates. On the other hand PPC is a binary system whereas as LC3 is ternary system, by comparing both it is clear that the early strength gain during first 7 days is more in LC3 concrete which resolves the problem of low strength gain at early ages.
4.2 Split Tensile Strength and Flexural Strength Test:

Figures 2, 3 shows the results of M 30 grade concrete with different types of binders. It is exhibited that split tensile strength is almost similar in all types of concrete irrespective of type of binder. From Figure 3, it is clear that enhanced performance of LC3 concrete is noticed when compared with OPC and PPC based concretes. An average of 15% increase in flexural strength is observed in LC3 concrete. This is due to the dense compact morphology of LC3 develops the crack bridge in the inner layer structure by forming silicon chains.
4.3 RCPT Results:

Table 3 shows the result for rapid chloride ion penetration test for M30 grade concrete with different types of binders. From the values of current and charge passed through specimen it is evident the ingress of chloride ions into LC3 concrete specimens is less compared to other specimens. From this it is clear that the durability of LC3 concrete specimens are enhanced with the RCPT results, i.e 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. By using LC3 binder, the chloride resistance is enhanced by about 85-90% when compared to OPC and PPC based concretes.

Table 3: Rapid Chloride ion Penetration Test Results of M30 grade concrete with different binders

| S.No. | Mixes | Charge passed (Coulombs) | Chloride ion permeability as per ASTM C 1202 |
|-------|-------|--------------------------|---------------------------------------------|
| 1     | AO    | 1632                     | Low                                         |
| 2     | AL    | 817                      | Very Low                                   |
| 3     | AP    | 1385                     | Low                                         |
4.4 Absorption and Desorption Test Results:
In addition to RCP test, Absorption and Desorption tests were also conducted to get more qualitative results for M 30 grade concrete with different binders. From Figure 4, it is evident that the rate of absorption all specimens is linear upto 24 hours after that the curve is almost straight for all specimens irrespective of type of binder. From the graph, it is clear that LC3 concrete specimen shown lesser water absorption when compared to OPC and PPC based concrete specimens. 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 of water absorption is less in case of LC3 concrete, whereas in OPC based concrete specimens the rate of water absorption is more due to less dense microstructure and inter connectivity of pores is more as compared to PPC based concrete. Ternary blended and binary blended cements are more durable than that of OPC due to the effect of fine grained particles and compact core structure of concrete.

![Figure 4 Percentage of water Absorption for M30 grade concrete with different binders](image)

Figure 5 shows the percentages of water desorption for M 30 grade concrete with different binders. From figure, it is observed 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 the curves, it is found that the LC3 concrete specimens prone to less desorption compared to OPC and PPC concrete specimens. It is clear that the LC3 concrete has dense microstructure and compact core structure which does not allow the water desorption and this is mainly due to the
presence of finer particles in LC3 concrete and more reactivity pozzolana action is taken place which intern requires more amount of water to form secondary gel phase. There is a coincidence in durability and strength results, which helps to strengthen the performance of LC3 concrete in all aspects.

![Percentage of water desorption for M 30 grade concrete with different binders](image)

**Figure 5 Percentage of water desorption for M 30 grade concrete with different binders**

### 5. CONCLUSIONS

From the detailed experimental studies on mechanical and durability characteristics of LC3 concrete and comparison with OPC and PPC based concretes, the following are the findings.

- Concrete made with LC3 shows better strength when compared to OPC and PPC binder concretes. Based on 7 day strength of LC3, it is clear that early strength can be achieved through this pozzolanic material when compared to PPC.

- The performance of LC3 concrete is far better than that of OPC concrete especially in chloride ion penetration test. From results of RCPT, it is clear that LC3 concrete specimen observed less ingress of chloride ions compared to OPC and PPC concrete specimens, which is due to the presence of dense and uniform morphology.

- From absorption and desorption test results, it is evident that LC3 concrete specimen resulted in low permeability which could be a better in case of achieving good durable concrete. Enhanced properties of LC3 concrete are mainly due to the pore refinement and the dense microstructure.

- From over all studies, results suggested that the high performance pozzolana activity can be achieved through LC3 binder system without compromising the strength and durability properties when compared to OPC binder system.
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