LIME CALCINED CLAY CEMENT (LC3): A Review
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ABSTRACT
Discovery of alternative to the pozzolanic materials generated from industrial wastes was needed because of its unavailability when the industries was shutdown permanently. Consumption of pozzolanic materials in concrete will be a safer solution for this problem. Numerous studies were presented for utilization of fly ash, Ground Granular Blast Furnace Slag (GGBS), Metakaolin and silica fume as a pozzolanic material in concrete. LC3 is a type of cement by mixing of limestone, calcined clay and gypsum, a few literatures were available on LC3. This paper presents the overview of research work presented on physical, chemical, performance in cement mortars like consistency, setting times & compressive strength, properties of fresh & hardened concrete like workability, compressive strength, split tensile strength, flexure strength made LC3.

KEYWORDS: LC3, physical properties, cement mortar, compressive strength, and durability.

1. INTRODUCTION
Infrastructure and construction sectors have always been the key indicators of growth and prosperity of a country’s economy [1]. The use of supplementary cementitious materials (SCMs) replacing conventional materials has a huge potential to reduce carbon emissions and precious resource consumption in cement production, especially for developing countries [2]. Introducing environment friendly materials is one of the most fascinating and highly preferred research fields in engineering. In civil engineering and related disciplines, concrete is a high-demand material for the building and construction sector. We can observe a production of nearly 1 ton of CO2 production of every ton of ordinary Portland cement (OPC) [3]. Being one of the most significant sources of greenhouse gases, the cement industry is responsible for about 7% of the total CO2 emissions worldwide. Today> 80% of SCMs used to reduce the clinker factor in cement are either limestone, fly ash or slag. Cement production in 2014 was 4.3 billion tonnes. Emerging economies (China, India, CIS, others Asia) account for roughly 3.5 billion tonnes, 81% of the world's production. Industrialized countries (Europe, USA, Japan) produced roughly 0.4 billion tonnes, 9% of the
world's cement production. Calcined clays, particularly in combination with limestone (LC3 technology) have tremendous potential to extend the use of supplementary cementitious materials as a partial replacement of clinker in cement and concrete [4].

In a recent joint research between Cuba and Switzerland, a new ternary blended cement called Limestone Calcined Clay Cement (LC3), which can contain as little as 50% clinker by using calcined clay and limestone, was developed. Studies show that LC3, can give similar or better performance than OPC and PPC in many aspects. Optimal composition in LC3 and its chemistry has also been explained in previous studies. It was observed from the first pilot scale production of LC3 in India that a good performance of the cement can be achieved even from clays with very low kaolinitic content.

The kaolinite clay available in India has been found to have pozzolanic properties which upon being heated up to 800 °C undergoes dihydroxylation and converts into reactive pozzolana [5]. Mono carboaluminates have been observed as a hydration product in limestone blended cements which is found to be more stable than mono sulphoaluminate in the presence of limestone [6]. In this paper we study about the properties in a deeper manner. This paper reports a review on the utilization of LC3 in cement mortar as well as concrete.

2. LC3 MATERIALS

The essential materials used in preparation of LC3 blend are Clinker, Calcined clay, Limestone and Gypsum.

2.1 Clinker

Clinker is produced by heating Calcareous and Aluminous material at 1400°C during this heating process, 60 to 62% of carbon dioxide is liberated. The clinker produced after heating will be in forms of lumps displayed in Figure. 1.

![Figure.1: clinker in lumps form](image-url)
In LC3, clinker content is reduced to 50% thereby carbon dioxide emissions were reduced to 30% lower than OPC and 11% lower than PPC [5]. The various proportions of clinker content used in this study are 40%, 50% and 60%.

2.2 Calcined clay
Clay that is rich in kaolin mineral around greater than 40% is suitable for LC3. Clay can be calcined in conventional rotary kilns, flash calcination unit, roller hearth kilns, shuttle kilns and muffle furnace [6]. When clay containing Kaolin is calcined, metakaolin is formed which contains aluminosilicate which reacts with calcium hydroxide as conventional pozzolana to give csh gel and Aluminium hydrate. In addition, the Alumina can react with limestone to produce carboalumination hydrates.

2.3 Limestone
LC3 can increase the life of mines by reducing wastage of raw material. Low calcite limestone with impurities like dolomite and quartz can be used in LC3 along with limestone that is not suitable for clinker production can also be used in LC3. A new ternary blended cement has been developed based on the combination of Portland cement with calcined clay and limestone ultimately with low quality-overburden material that is normally considered waste for traditional production: low-grade clay and dolomite rich limestone. Firing takes place at half the clinkerization temperature. As the Limestone is not calcined, thus it is does not contribute to an increase in CO$_2$ emissions. Three industrial trial productions and several laboratory trial productions of limestone calcined clay cement in India was carried out between 2014 to 2017, Figure 2. displays the calcined clay at different temperatures [7].

Figure 2. Calcined clay at different temperatures
The calcium carbonate supplied through limestone to the system and the extra alumina provided by calcined clay will further react to form alumina phases. The material has a residence time of around 60 min at the firing chamber, and the reactivity achieved is reasonably good [8] [9]. Flash calcination takes place in special flash calciners. The original clayey material should be previously dried and ground to powder. It is then fed to a stream of hot gas at temperatures of around 800–900 °C with residence time of a few seconds. The technology enables implementation of several heat recovery cycles, thus the potential for efficiency is high, with power consumption in the rate of 2211 MJ/t of metakaolin flash [10]. Few authors made the comparison between LC3 with OPC as well as PPC, Table 1. Displays the chemical composition.

Table 1: Chemical composition of materials used in the study.

| S. No | Component | OPC (%) | PPC (%) | LC3 (%) |
|-------|-----------|---------|---------|---------|
|       |           | Clinker | Calcined clay | limestone |
| 1     | CaO       | 64.59   | 63.81   | 0.09    | 48054   |
| 2     | SiO2      | 19.01   | 21.12   | 54.43   | 10.7    |
| 3     | Al2O3     | 4.17    | 5.24    | 24.95   | 1.74    |
| 4     | Fe2O3     | 3.89    | 3.41    | 5.08    | 1.62    |
| 5     | MgO       | 0.88    | 3.06    | 0.19    | 0.467   |
| 6     | Mn2O3     | -       | 0.06    | -       | 0.035   |
| 7     | Na2O      | 0.16    | 0.32    | 0.05    | -       |
| 8     | K2O       | 0.59    | 0.19    | 0.21    | 0.13    |
| 9     | TiO2      | 0.23    | 0.10    | 1.41    | 0.206   |
| 10    | SO3       | 1.70    | 0.63    | -       | 0.01    |
| 11    | LOI       | 1.40    | 0.98    | 9.58    | 37.09   |

3. PROPERTIES OF LC3:
3.1 Physical and chemical properties
Few authors reported on the properties of LC3 composition, plenty of ambiguity in the physical properties of calcined due to its source of collection. The comparison was done with OPC as well as PPC, Table 2. displays the comparison between physical properties of LC3 [11].
### 3.2 Cement Mortar

The authors performed plenty of tests on LC3 mortars, reported that the LC3 exhibits almost same compressive strength as OPC 43 grade cement. It is also key to mention that w/c was fixed based on the standard consistency measured, so the LC3 system had higher w/c ratio based on the consistency. Lower workability was reported upon blending the calcined bentonite to the cement mortar.

### 3.3 Cement concrete

Several concrete mixtures were designed and produced in the laboratory using all the blends of LC3, OPC and PPC. Polycarboxylate Ether based chemical admixture was used to achieve a slump in the range of 75 mm to 100 mm as the was found to give the best flow with LC3 blends. LC3 shown better strength properties than OPC and PPC.[12] Perhaps due to the non-uniform calcination of the clays, a large batch-to-batch variation in the strengths of the concrete was observed, however, it was generally observed that for a given water to cement ratio, LC3 shown better performance and all most all equals with PPC. The substitution of cement by calcined kaolinite resulted in a considerable increase in strength from 7 days compared to the control mortar. This increase is explained by the pozzolanic character of the calcined clay that combines CH to form additional C–S–H, filling more space and thus increasing the mechanical properties.

### 3.4 Carbonation of concrete

The carbonation depths deduced from phenolphthalein indicator test together with the scatters up to 8 weeks exposure to 1% CO2 and after 30 weeks of natural carbonation. OPC-50 specimens exposed to 1% CO2 did not show any clear carbonation front. No carbonation front could be report for OPC-50. Overall, results show that the resistance of LC3 concrete against carbonation is reducing when increasing the OPC substitution rate. It shows the LC3 performed against the carbonation of concrete in better manner than that of PPC and OPC.
3.5 Porosity
Munisamy et. al., 2018, performed few tests to assess the porosity of mortar with a prism of 40 mm × 40 mm × 160 mm in size of specimens based on the study of [12]. The reported the increment in the porosity by incorporating the LC3 in the concrete.

3.6 Alkali silica reaction
M. S. H. khan et. al., 2018, performed the test on alkali silica reaction. The clay tested in LC3-65 and LC3-50 contain 50% of calcined kaolinite. The mortar bars after curing in fog condition for 28 days were soaked in 0.32 M of NaOH solutions at 38˚C [13]. Generally, the use of supplementary cementing materials has an effective preventive effect against alkali silica reaction in concrete due to the lower alkalinity and the presence of Al in pore solution [14].

4 APPLICATIONS OF LC3
Building materials such as Micro Concrete Roofing Tiles (MCR), solid concrete bricks, autoclaved aerated concrete (AAC) blocks, RCC door and window frames and paving blocks were produced using LC 3. The building materials were found to meet the requirements of the relevant standard, without any changes to the usual mixture designs and production processes. Most importantly, it was found that no retraining of the workers or re-calibration of equipment was required when ordinary Portland or pozzolanic cements were replaced by LC3 during these productions. A two-storey building, having plain and reinforced concrete elements was built in central India, completely using LC3. It was once again found that no retraining of the workers was required to use the cements and no major changes to mixture designs were required to produce concretes like those usually used in such construction [15]. These observations are important to demonstrate the applicability of LC3 in general use applications, as a replacement of OPC or PPC. Additionally, to test the suitability of the cement in automated production processes, concrete paver blocks and autoclaved aerated concrete (AAC) blocks were produced in fully automated plants. It was once again found that only minor modifications to mixture designs were required for the production and the products still met the requirements of the standards. The AAC blocks were used for the construction of the walls of a building in the complex of the Swiss Embassy in New Delhi, without any change needed in the construction process.

5. CONCLUSIONS
Plenty investigations were conducted by to evaluate the properties of LC3 mortar as well as concrete. The subsequent conclusions were drawn based on their reported results. In this constrained context, this study has shown that LC3 represent a grounded alternative. This study has assessed, from both an economic and environmental point of view, three cements that can be produced in Cuba. The LC3 technology, which involve the combination of 50% of clinker, 15% of unburned limestone and 30% of calcined clay (and 5% Gypsum), was an energy and cost efficient technology. Savings in term of greenhouse gas emissions as well as production and investment costs were significant. The presented results take into account a number of variables and are robust. LC3 had therefore great potential to provide a viable opportunity to meet an increase in cement demand with low CO2 released and low dollar investment. Despite the problems in the production of the LC3 blends, it was found that the blends that used the higher quality clays consistently gave better strengths that the OPC in mortars, concretes and building materials despite having less than 40% calcined kaolinite content in the calcined clay used.

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