



Limestone Calcined Clay Cement as A Green Construction Material

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ABSTRACT

Supplementary Cementitious Materials (SCMs) are promising components as substitutes for clinker components in cement and at the same time become a solution in reducing CO₂ emissions and increasing sustainable development. The main objective of this study is to focus on production, techno-economic feasibility, and environmental impact, and cost-effectiveness of the limestone calcined clay cement (LC3). LC3 is a new type of cement-based on a blend of limestone and calcined clay. A combination of calcined clay with limestone allows higher levels of substitution down to clinker contents of around 50% with similar mechanical properties and improvement in some aspects of durability. The results showed that the feasibility of blending 50% of LC3 in cement. The hope is that these findings can help reduce carbon footprints in the construction industry.

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1. INTRODUCTION

The limited supplies of conventional supplementary cementitious materials (SCMs) make it difficult to take this strategy further unless new types of SCMs become available. The only type of material available in the quantities needed to meet demand is clay containing kaolinite, which can be calcined to produce an effective SCM. Traditional Portland cement consists of 95% clinker. The production of it is energy-intensive and responsible for most of the CO₂ within the cement. By reducing the clinker-content with so-called Supplementary Cementitious Materials (SCMs), large CO₂ savings can be achieved (Rahla et al., 2019; Juenger et al., 2019).

Limestone calcined clay cement LC³ is a new blend of two materials that have a synergetic effect. LC³ can reduce CO₂ emissions by up to 40%. It is made using limestone and low-grade clays which are available in abundant quantities. It is cost-effective and does not require expensive modifications to existing cement plants. LC³ uses industrial waste materials which thereby increase resource efficiency and reduce the utilization of the scarce raw materials that are necessary for producing clinker (Avet et al., 2019). In other applications, LC³ has the potential for applications used in prestressed and post-tensioned concrete members, used in masonry mortars and plastering, used in decorative and art structures, used in the manufacture of precast sewage pipes, used under harsh concrete conditions (Krishnan et al., 2018). **Table 1** shows the chemical composition of LC³ (Scrivener et al., 2018).

In this study, the objective of the LC³ project is to research, testing and making LC³ standard and mainstream general use cement in the global cement market. The main research activities focus on production, environmental sustainability, techno-economic feasibility, and cost-effectiveness of the LC³.

Table 1. Chemical Composition of LC³.

Chemical Composition	Percentage (%)
Clinker	50
Calcined Clay	30
Limestone	15
Gypsum	5

2. METHODS

The raw materials needed to produce mixed LC³ - ordinary Portland cement (OPC) are clinker, limestone, kaolinite clay, and gypsum. To produce LC³, here are the steps: i) Clinker burnt at very high temperatures between 1400 and 1500°C, ii) Calcined clays are burnt at approximately 800°C, and iii) addition of limestone and gypsum to produce. In LC³ production, gypsum content was varied (20, 35, 51, 80, and 95%).

Furthermore, the clinker used to produce LC³ was also ground along with 5% gypsum to produce ordinary Portland cement (OPC) for comparison with the LC³ blends. After the LC³ and OPC were prepared, they were mixed with a mixture ratio of 60% LC³ and 40% OPC. **Figure 1** is an illustration of LC³ production.

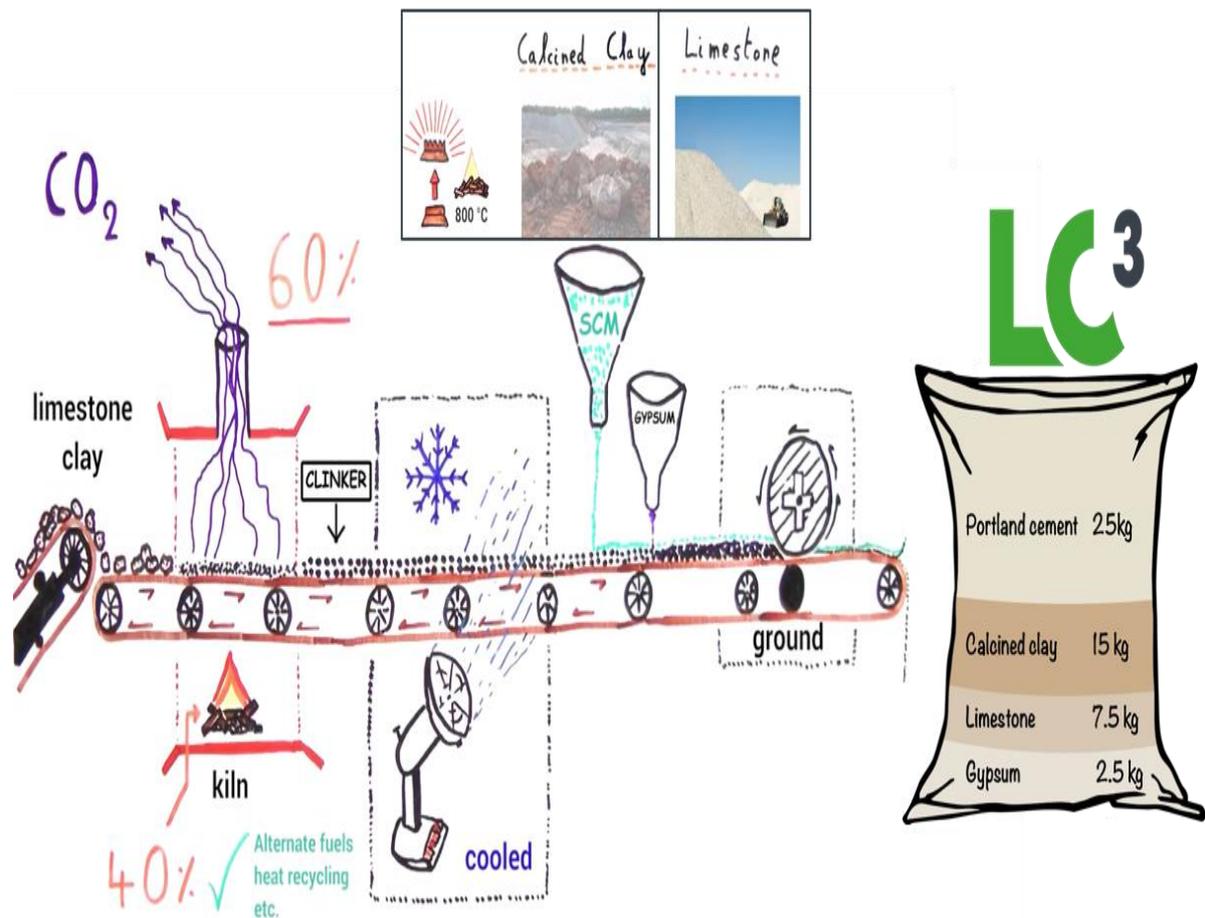


Figure 1. Illustration of LC³ production.

3. RESULTS AND DISCUSSION

LC³ has been used in many different regions and different scales. Overall, more than 25 applications were already built with LC³. **Figure 2** is the most prominent project is the model Jhansi, India. This house is made of 98% of LC³ and it used 26.6 tons of industrial waste (192kg/sqm) and saved 15.5t of CO₂ (114 kg/sqm). These CO₂ savings are similar to the emissions of 10 passengers traveling by plane from Switzerland to South Africa.

There are also numerous other projects in India. For example, **Figure 3** is the offices of the Swiss Agency for Development and Cooperation in the compound of the Swiss Embassy in Delhi that were built with LC³- prefab materials. Furthermore, **Figure 4** is some roads, a check dam, and pavements that have been built.

In Latin America, several applications have been built. They are mainly in Cuba and also in other countries. Among those applications are an LC³ house (**Figure 5**), pavements (**Figure 6**), testing sites in the sea, and art sculptures (**Figure 7**).



Figure 2. Model house in Jhansi.



Figure 3. Swiss Embassy building in Delhi.



Figure 4. Dam in Orchha.



Figure 5. Model house in Santa Clara.



Figure 6. LC³ pavements at UCLV.



Figure 7. LC³ for Biennale.

3.1. Engineering Perspective

3.1.1. Compressive strength

LC³ 60% - OPC 40% mix compressive strength gives 3.98% more than conventional concrete. Investigation of the influence of the gypsum content (20, 35, 51, 80, and 95%) on the compressive strength of LC³ cement was carried out. For the accomplishment of the study 6 mortars were produced. For the hardened state analysis, the compressive strengths were compared at the ages of 1, 3, 7, 28, and 91 days. From the result obtained it was possible to verify that gypsum content influences the compressive strength of the LC³ cement. The highest mechanical strengths were obtained with the use of larger quantities of gypsum. **Figure 8** shows the compressive strength of LC³.

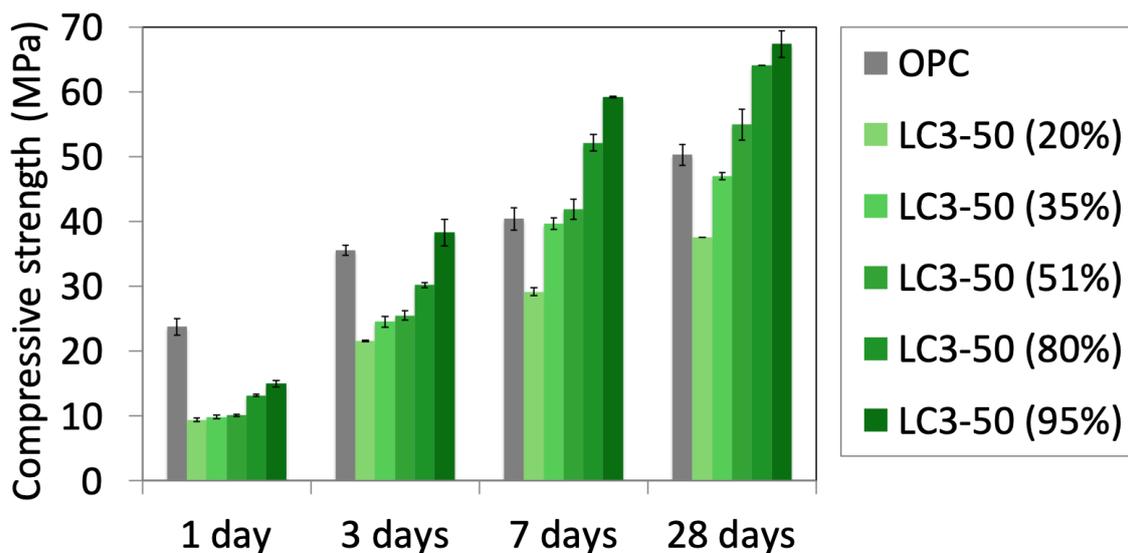


Figure 8. Compressive strength of LC³.

3.1.2. Fineness

The effect of fineness of the different components in a blend containing 40% Portland cement and 60% of LC³. The higher fineness of both clinker and calcined clay can considerably improve compressive strength.

3.1.3. Durability

An extensive testing program is underway, including both laboratory and natural exposure studies. The results so far indicate:

- i) Good protection of reinforcement
- ii) Excellent resistance to chloride penetration
- iii) Good mitigation of ASR with reactive aggregates
- iv) Good performance in presence of sulfates
- v) Carbonation comparable to other blended cement

The phases in LC³ cement are the same as those present in blended cement currently widely used in practice. However, there is a high degree of refinement. The kinetics of pore refinement depends on the original kaolinite content of the calcined clay. In fact, at 28 days, all cement pastes made with calcined clays, even those with very low original kaolinite content; have a pore structure finer than pastes made with Portland cement.

3.2. Techno-Economic Feasibility of LC³

LC³ is very competitive in performance and economic terms. It shows very similar performance characteristics compared to conventional Portland cement and even outperforms traditional cement in some regards such as resistance to chloride and alkali-silica reaction (called ASR or “concrete cancer”). Apart from the laboratory testing at EPFL and the IITs, several applications have been constructed and they showed very positive results.

LC³ is up to 25% cheaper in production due to the reduction of the energy-intensive clinker content with widely available and less energy-intensive materials. Investment costs are also low since already existing technologies can be used for the production of LC³. Moreover, this existing economic attractiveness can be further increased by governments through incentives such as tax reductions to accelerate the production of LC³.

LC³ is a ternary cement that can achieve strengths similar to OPC even at clinker factors as low as 40% to 50%. The remaining cement is a blend of crushed limestone and calcined clay. LC³ promises to support sustainable growth by reducing emissions, energy consumption, capital and production costs, and wastage of raw materials. LC³ has been developed in an international collaboration between the University of Las Villas, Cuba, and Ecole Polytechnique Fédérale de Lausanne, Switzerland, which was funded by the Swiss government.

LC³ takes advantage of the synergetic hydration of clinker, calcined clay, and crushed limestone to achieve the performance required from commercial cements, even at clinker factors as low as 0.40. The low-quality limestone and clay used in the LC³ blend ensure that the cement can be produced at costs lower, without the risk of unsoundness. Since clays with low kaolinite contents, after calcination at relatively lower temperatures of 700°C to 800°C, can be used along with low calcite limestones with impurities such as quartz and dolomite, this cement can reduce wastage of raw materials and increase the life of mines. The lower processing required in the ingredients of LC³ ensures a lower capital investment required for the same incremental increase in production capacity.

3.3. Global Impact on LC³

On a global level, it is estimated that the utilization of LC³ instead of regular cement can save up to 400 million tons of CO₂ per year by 2050. This amount equals France’s entire yearly carbon dioxide emissions. When looking at LC³ in terms of frameworks such as the United Nations Sustainable Development Goals (SDGs), its potential to contribute to climate action efforts becomes clear. Among other contributions, LC³- Low Carbon Cement can be directly associated with 5 of the 17 Sustainable Development Goals. **Figure 9** shows associated with 5 of the 17 Sustainable Development Goals.



Figure 9. Associated with 5 of the 17 sustainable development goals.

4. CONCLUSION

Climate protection and development efforts are essential for a sustainable environment. LC3 is the answer to both of these important goals together. Construction projects can now be realized with a more efficient material which thereby saves 30% of CO₂ emissions. Hence, LC3 is a solution for well-adapted sustainable development ambitions.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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