



Journal of Materials and Engineering Structures

Research Paper

Innovations in Green Construction: A Comprehensive Review of Limestone Calcined Clay Cement

Vikas Gholap ^a, Sachin B Mulay ^b, Pramod K Kolse ^c

^a Research Scholar, Civil Engineering Department, Sandip University, Nashik, India.

and Assistant Professor, Pravara Rural Engineering College, Loni, India.

^b Professor, Civil Engineering Department, Sandip University, Nashik, India.

^c Associate Professor, Civil Engineering Department, Pravara Rural Engineering College, Loni, India.

ARTICLE INFO

Article history :

Received 20 January 2025

Revised 7 August 2025

Accepted 13 August 2025

Keywords:

Calcined Clay Cement

Cementitious Materials

Kaolinite

Limestone

ABSTRACT

Cement production is a major environmental concern, releasing nearly one tonne of carbon dioxide for every tonne of cement produced making it one of the largest industrial contributors to global CO₂ emissions. Limestone Calcined Clay Cement concrete is a new type of concrete that uses a mix of limestone and calcined clay as its binder. Combining limestone and calcined clay creates a low-clinker cement blend with impressive early-age strength. The durability of these cement systems is closely linked to their pore structure, which directly impacts how easily substances can move through the material. It is an eco-friendly, cost-effective, and high-performing option, offering a sustainable alternative to traditional Portland cement. This review paper provides insights into the edge-cutting features of LC3, manufacturing process of LC3. This review paper also details the emphasis on composition, properties, and applications of LC3. The review paper summarizes the findings from the numerous literature surveys, research gaps, and further areas for research and development.

1 Introduction

Portland cement has been used in construction for over 200 years, showing its reliability in various conditions [1]. It is the most widely produced material globally, highlighting its success. Over time, both its production methods and applications undergone significant evolution. The cement industry is responsible for a substantial share of global greenhouse gas emissions, contributing about 5–8% of the total [2]. Due to this issue, it is essential to identify an alternative to industrial waste-based pozzolanic materials. It has also been revealed that using pozzolanic materials in concrete provides a reliable and safe solution to this problem. Replacing a portion of clinker with supplementary materials is the most effective approach to lowering CO₂ emissions in the cement industry worldwide [3]. LC3 represents an innovative and environmentally friendly

* Corresponding author.

E-mail address: author@institute.xxx

e-ISSN: 2170-127X,

alternative to conventional cement, offering substantial potential for reducing carbon emissions within the cement industry [4, 5]. This sustainable material is characterized by its low-carbon footprint, achieved through a unique combination of ingredients. LC3 is produced by blending finely ground limestone with calcined clay, a specially treated type of clay that undergoes thermal activation at elevated temperatures [6, 7]. LC3 offers an accelerated initial setting time and enhances the durability and elasticity [8]. The behaviour of the LC3 paste was evaluated across a range of temperatures, specifically 10 °C, 20 °C, 40 °C, and 60 °C [9]. Notably, even though the concentrations of calcium, silica, and aluminum varied between samples, both LC3 and OPC pastes exhibited comparable levels of water absorption [10]. This indicates that the variations in chemical composition did not significantly influence the water absorption capacity of the two materials, suggesting similar performance in this particular aspect under the specified conditions [11].

The incorporation of calcined clay in LC3 offers numerous advantages, both practical and environmental. One significant benefit is the abundant availability of raw materials calcined clay and limestone on a global scale. This widespread accessibility ensures that LC3 production can be implemented in various regions without the need for extensive logistical challenges or dependency on rare resources. This contributes to the sustainability of LC3, as it promotes the use of locally available materials while reducing the carbon footprint associated with the transport of raw materials. Additionally, LC3 production integrates naturally into the existing infrastructure of the cement industry.

The manufacturing process relies on established techniques and equipment already familiar to industry professionals. This compatibility eliminates the need for specialized machinery or extensive retraining of the workforce, facilitating its adoption at scale. Consequently, cement manufacturers can transition to LC3 production with minimal operational disruption or financial burden, accelerating the industry's shift toward more sustainable construction materials. These factors, combined with the environmental benefits of reduced carbon emissions associated with LC3, underscore its potential as a practical, cost-effective, and eco-friendly alternative to traditional cement.

Research gap indicates the LC3 has shown significant promise as a low-carbon alternative to conventional Portland cement, but its practical application in green construction projects need to explore in detail. Most Available literature have focused on laboratory-scale evaluations, with insufficient field data on LC3 efficiency in actual building environments. This review paper emphasis an in-depth examination of the existing application of LC3 in the concrete. This paper also insights its unique mechanical performance, durability features, sustainability benefits, limitations, future prospects, and implementation in practice. The review primarily emphasizes the technical and engineering features of LC3.

2 Manufacturing process of LC3

The manufacturing process of LC3 integrates traditional cement production techniques, which incorporate calcined clay and limestone as key components. This innovative process can be broadly divided into several stages, such as selection and preparation of raw material used, calcination of clay, residue production, mixing and grinding, inspection of quality control and testing, and the last stage is packaging and distribution. All the stages of production are crucial for ensuring the desired properties and performance of LC3.

Calcination is a basic thermal treatment process in which a material is subjected to high temperatures, typically in the presence of air or oxygen, to induce a chemical transformation [12]. This process helps modifying the structure, composition, and properties of the material by driving off volatile components or causing a solid-state reaction [13]. In the case of clay, the process involves heating it to temperatures ranging from 700 to 850 °C. At these temperatures, the clay undergoes significant physical and chemical changes, primarily due to the decomposition of minerals like kaolinite [14]. Metakaolin is produced by heating kaolinite-rich clays to temperatures in a range 650 to 850°C. It is the most important pozzolanic phase responsible for improving the binder's properties. It is also primarily responsible for the chemical reactivity that drives the performance benefits of LC3. The reactivity of metakaolin is depends on moisture present in the atmospheric, purity, and crystallinity of clay used. It must be free from iron oxides, quartz, and complete Calcination required. It is a challenging to maintain mineralogical purity, particle size, and long-term storage, The heat causes the clay's water content to evaporate and triggers the breakdown of silicate minerals into more stable forms. As a result, the calcined clay becomes reactive, making it suitable for use in applications such as cement production, where its properties contribute to enhanced strength and durability.

The precise temperature control during calcination ensures the clay reaches the desired level of reactivity without excessive degradation. The majority of research on LC3 has concentrated predominantly on kaolinite-rich clays due to their high pozzolanic reactivity, which makes them particularly effective in cementitious systems. However, the potential of other

clay types, such as illite (2:1 clay mineral) and montmorillonite (2:1 clay mineral with higher capacity for swelling), remains relatively underexplored. These clays, which are more abundant in some regions, exhibit lower reactivity compared to kaolinite, presenting challenges in achieving the desired performance outcomes in cement applications. Studies investigating the influence of kaolinite content have demonstrated that increasing its proportion in clays to levels exceeding 60% does not yield substantial improvements in compressive strength. This finding suggests a threshold beyond which the benefits of kaolinite addition moderate, potentially due to saturation of the reactive capacity within the binder system. Additionally, the performance characteristics of LC3, including its fresh-state workability, hydration kinetics, and hardened-state compressive strength, have been shown to depend heavily on the proportions of limestone, calcined clay, and supplementary materials. Limestone Calcined Clay is designated as LC2. It is a specific type of sag, which can vary between 0.9 and 2.5, and plays a critical role in determining the material's properties. Particle fineness has a significant influence on hydration, workability, durability, and development of strength. Furthermore, the incorporation of gypsum, typically in the range of 2% to 4% by weight of the total binder, has been identified as a key factor influencing the hydration process and the resultant mechanical strength. Gypsum contributes to the optimization of sulfate balance, facilitating the formation of hydration crystals, and enhancing the binder's overall performance. Non-kaolinitic clays are basically less reactive than the Metakaolin. But they can be utilized to improve the microstructure.

Composition, Properties, and Applications of LC3

LC3 is an innovative and environmentally friendly cement that reduces CO₂ emissions compared to traditional Ordinary Portland Cement (OPC). It is a ternary blend cement composed primarily of clinker (50-60%), calcined clay (15-35%), limestone (15-20%), with the optional addition of gypsum (5%) for setting regulation. Fig 1. Elaborate the composition of LC3. Clinker contains phases such as tricalcium silicate (C₃S), dicalcium silicate (C₂S), tricalcium aluminate (C₃A), and tetracalcium aluminoferrite (C₄AF). It enables the fundamental hydraulic characteristics of cement during its interaction with water. It boosts initial strength formation. LC3 achieves a significant reduction in CO₂ emissions by requiring less clinker than OPC.

Calcined clay contains abundant kaolinite (Al₂Si₂O₅(OH)₄), which converts to metakaolin (Al₂Si₂O₇) upon calcination at 600–850°C. Reacts as a pozzolan with calcium hydroxide (CH) produced in clinker hydration, resulting in additional calcium silicate hydrates (C-S-H). Kaolinitic clay is chosen because of its excellent reactivity after-calcination. To produce cost effective LC3, low grade clays with 40-60%, kaolinite content can also be used. Concrete produced with LC3 has been rigorously tested, demonstrating exceptional mechanical strength and superior durability. It notably surpasses Ordinary Portland Cement (OPC) in resisting chloride penetration, minimizing gas permeability, and reducing capillary water absorption. Furthermore, its performance rivals that of concrete made with fly ash, solidifying LC3's position as a high-performance and eco-friendly alternative in modern construction. This process enhances the reactivity of the clay, making it an effective component in cement production while simultaneously minimizing the reliance on clinker, the most carbon-intensive element in traditional cement. The alumina present in the calcined clay interacts with the carbonate found in the limestone, resulting in the formation of a specialized compound known as the carboaluminate phase [15]. Therefore, approximately 15-20 % limestone is used in the production of LC3. It reduces the CO₂ emission, enhance the durability and workability of the concrete. To control the setting time of the cement gypsum is added around 5% in the manufacturing LC3. This phase plays a critical role in enhancing the performance of the cement. Specifically, the carboaluminate contributes to the overall strength and durability of the material by improving the microstructure of the hardened cement matrix [16]. This improved microstructure helps in binding the components more effectively, reducing porosity, and increasing resistance to external factors such as water penetration, chemical attack, and mechanical stress [17]. Consequently, the formation of the carboaluminate phase is a key factor in ensuring the long-term structural integrity and reliability of cement produced using limestone and calcined clay [18].

LC3 is an innovative material in the field of construction, offering a sustainable alternative to ordinary Portland cement (OPC). A thorough understanding of LC3 requires an exploration of its fundamental characteristics, spanning both micro- and macro-level mechanisms. This includes analyzing its chemical composition, hydration chemistry, phase evolution, and overall performance under various conditions. The mechanisms of hydration retardation depend on the physical and chemical properties, the microstructure of the mix design, ion adsorption by calcined clay, formation of an aluminate-rich layer, clinker content, and the presence of high alumina levels.

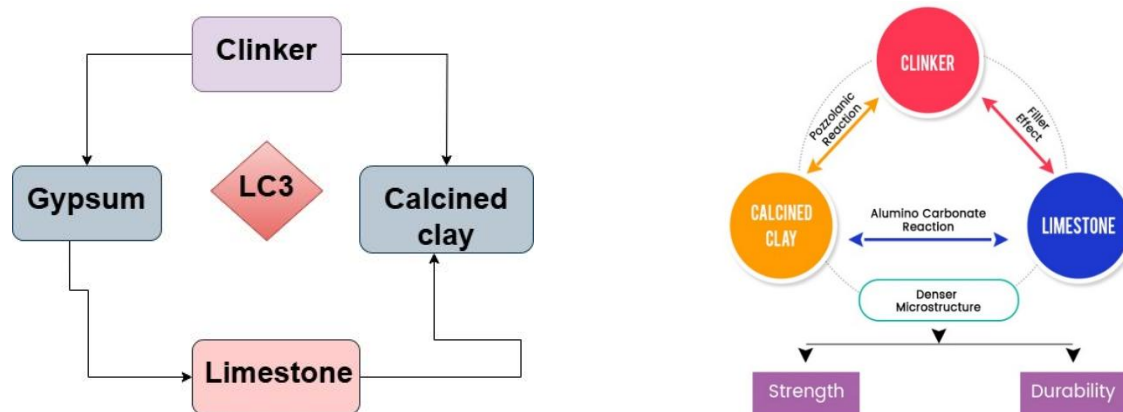


Fig. 1 - Composition of LC3 [1].

Chemical Composition and Hydration Chemistry

LC3 is primarily composed of limestone, calcined clay, clinker, and gypsum. The synergistic reaction between these components during hydration produces a unique phase accumulation. Calcined clay, rich in metakaolin, enhances the pozzolanic reaction, leading to the formation of additional calcium silicate hydrates (C-S-H) and alumina-containing phases such as stratlingite. These phases contribute to improved microstructural density and durability. The specific composition of the raw materials, particularly the alumina content in the calcined clay and the mineralogical profile of the clinker, plays a pivotal role in determining the final properties of LC3. These parameters can vary significantly based on regional resource availability.

Phase Accumulation and Impact of Salts

During hydration, LC3 develops a complex phase assemblage influenced by its unique chemical interactions. The presence of limestone promotes the stabilization of monocarboaluminate instead of monosulfate, enhancing durability. When exposed to salts such as chlorides and sulfates, LC3 demonstrates notable resistance due to its refined pore structure and dense matrix. This resistance minimizes the ingress of harmful ions, thereby extending the lifespan of concrete structures in aggressive environments.

Carbonation Effects

LC3 exhibits a distinct carbonation behaviour compared to OPC. The fine balance between limestone and calcined clay influences the carbonation process, which can result in changes to the microstructure and mechanical properties over time. The refined pore network in LC3 slows down the penetration of carbon dioxide, offering long-term stability even under carbonation-prone conditions.

Rheological Properties

The workability and flow characteristics of LC3 are governed by its particle size distribution and the interaction between its constituents. The fine particles of calcined clay improve water retention, while the presence of limestone enhances lubrication. Together, these properties make LC3 suitable for a wide range of construction applications, from precast elements to large-scale pours.

Mechanical Behaviour

In terms of mechanical performance, LC3 matches or exceeds OPC in most applications. The combination of pozzolanic reactions and optimized phase assemblage results in high compressive strength and reduced permeability. These features contribute to the material's ability to withstand mechanical stresses and environmental degradation.

High-Temperature Exposure

When subjected to elevated temperatures, LC3 shows commendable stability. The reduced content of calcium hydroxide, due to the presence of supplementary cementitious materials (SCMs), minimizes the risk of thermal cracking. This makes LC3 an excellent choice for fire-resistant structures and high-temperature applications.

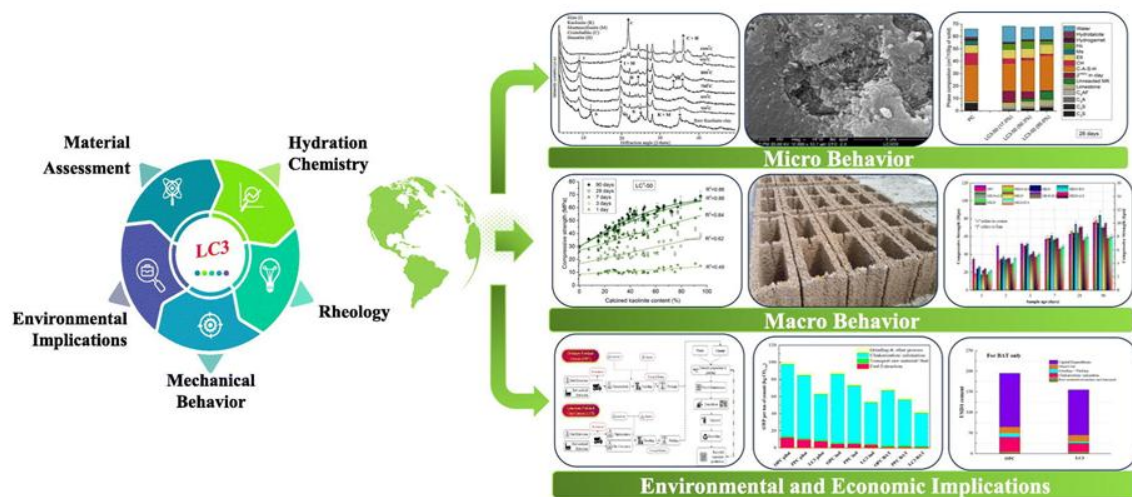


Fig. 2 - Process of LC3 formation and its application [19]

Compatibility with Admixtures

LC3 demonstrates good compatibility with a wide range of chemical admixtures, including superplasticizers and accelerators. This adaptability allows for tailoring the mix design to meet specific performance requirements, whether for enhanced workability, rapid strength gain, or improved durability.

Environmental Resistance

One of LC3's standout properties is its superior resistance to alkali-silica reactions (ASR) and sulfate-induced degradation. The reduced alkali content and optimized pore structure limit the expansion caused by reactive aggregates, making LC3 ideal for structures in environments prone to these challenges. Additionally, its heightened resistance to chloride ingress makes it particularly suitable for marine construction and chloride-rich environments.

Regional Variability in Performance

The performance of LC3 is strongly influenced by the characteristics of its raw materials, particularly the clinker composition and the alumina content in SCMs. These factors can vary significantly based on local geology, leading to regional differences in LC3's properties. Understanding and optimizing these variations is crucial for maximizing the material's potential in different contexts. In summary, LC3 is a versatile and sustainable cementitious material with exceptional durability, mechanical strength, and environmental resistance. Its adaptability to various conditions and compatibility with modern construction techniques position it as a highly promising solution for the future of sustainable infrastructure.

Recent development: Life Cycle Assessment (LCA) comparisons:

The energy demand for processing limestone and calcined clay is considerably lower than that of clinker. In recent years, LC3 has been extensively studied through Life Cycle Assessment (LCA) to understand its environmental impacts from production to end use. By conducting LCAs, experts aim to capture and quantify environmental factors such as carbon dioxide emissions, energy inputs, depletion of natural resources, and health/ecological consequences. According to LCA studies, LC3 offers a substantial 35–40% reduction in CO₂ emissions when compared to OPC, attributed mainly to its lower clinker content of roughly 50%, which limits calcination-related emissions.

Pilot Projects in India:

The Jhansi Model House (2014), JK Lakshmi IIT Delhi Pilot Plant (2017), and the Commercial Pilot Project for Noida International Airport (2023–24) successfully incorporated LC3 to reduce carbon emissions. These initiatives collectively achieved an estimated saving of 15.5 tonnes of CO₂ carbon credits, representing a 35% reduction in CO₂ emissions per ton of cement.

Scalability Challenges in industrial production:

Getting enough kaolinitic clay is still a challenge, especially in large quantities. The mineral content of the clay can vary, which affects how it reacts and the quality of the final product. A steady supply of limestone and gypsum is also very important. Improving the calcination process is not easy. Changes are needed in kilns, blending units, and material handling systems to support LC3 production. It is important to maintain consistent quality in every batch. Skilled workers and proper design knowledge are needed. Making the project economically viable is also a challenge, and setting up the plant requires investment.

2.1 Applications of LC3

The production of traditional Portland cement heavily relies on clinker, which constitutes 95% of its composition. This process is not only highly energy-intensive but also a significant contributor to CO₂ emissions in cement manufacturing. By replacing a substantial portion of clinker with Supplementary Cementitious Materials (SCMs), the industry can achieve remarkable Decreasing carbon emissions LC3 represents an innovative advancement in sustainable cement technology. This innovative blend leverages the synergistic interaction between limestone and calcined clay, enabling a reduction of up to 50% in clinker content. As a result, LC3 can lower CO₂ emissions by as much as 40%. Additionally, LC3 incorporates industrial by-products, promoting resource efficiency while reducing the dependence on finite raw materials typically required for clinker production. This sustainable approach not only minimizes environmental impact but also supports the transition to a more circular economy in the construction sector. LC3 offers a remarkable solution for Cutting CO₂ output, achieving up to 40% less CO₂ compared to Ordinary Portland Cement. A significant portion of these emissions originates from the clinker production process. Cutting down on clinker usage and replacing it with Supplementary Cementitious Materials (SCMs) presents the most efficient way to limiting carbon footprint.

The CO₂ emissions in clinker production stem from two primary sources. First, the process requires extreme temperatures ranging from 1400 to 1500°C, consuming large amounts of energy. Second, the chemical decomposition of limestone releases CO₂ inherently bound within it. By decreasing the reliance on clinker, LC3 simultaneously addresses energy-intensive emissions and the release of embodied CO₂, offering a dual advantage in mitigating environmental impact. Fig 3. Insights the details application of LC3 over the ordinary Portland cement, and Portland pozzolana cement.

Research on LC3 has identified a distinct relationship between the kaolinite content in calcined clays and the material's performance characteristics. Specifically, increasing the proportion of kaolinite in clays beyond 60% does not significantly enhance the compressive strength of the cement. This suggests a threshold beyond which additional kaolinite contributes minimally to the material's structural integrity. Moreover, clays with higher kaolinite content have been observed to interfere with the hydration process of clinker phases. Notably, the hydration of dicalcium silicate (C₂S), a critical component in clinker, is adversely affected. In the context of LC3-50 cement, which incorporates 50% clinker, the influence of calcined kaolinite content becomes pronounced. When the calcined kaolinite content exceeds 65%, the ongoing hydration of clinker phases is hindered, starting from the third day after mixing. A detailed analysis of this phenomenon reveals that the retardation of clinker hydration is closely linked to changes in the microstructure of the cement.

Specifically, the high calcined kaolinite content leads to a significant refinement of pore connectivity within the material. This microstructural alteration restricts the transport of water and ions, thereby slowing down the chemical reactions necessary for the hydration process. As a result, while higher kaolinite content may enhance certain properties, such as early strength development, it imposes limitations on the continued hydration and long-term performance of the cement. To evaluate the practicality of using LC3-50 and understand the impact of calcined kaolinite content on strength development, compressive strength tests were conducted. These tests aimed to investigate how varying levels of calcined kaolinite influence the mechanical properties of LC3-50. The findings highlight a correlation between calcined kaolinite content and the compressive strength of LC3-50, as documented in studies by Francois Avet et al. [20, 21] [Fig.4.]. The study examined the distinct physicochemical effects of calcined kaolinite (CK) and montmorillonite (CM) clays on the sulfate balance, early hydration behaviour, and artificial pore solution composition in LC3 [22]. The research focused on evaluating key parameters, including the influence of fineness, the dissolution kinetics of the clays, and their ion-adsorption capacities. These factors were analyzed using advanced techniques such as isothermal calorimetry to monitor heat evolution during hydration, compressive strength testing to assess mechanical performance, inductively coupled plasma optical emission spectrometry (ICP-OES) for ion concentration measurements, and zeta potential analysis to evaluate particle surface charges [22] [Fig.5.].

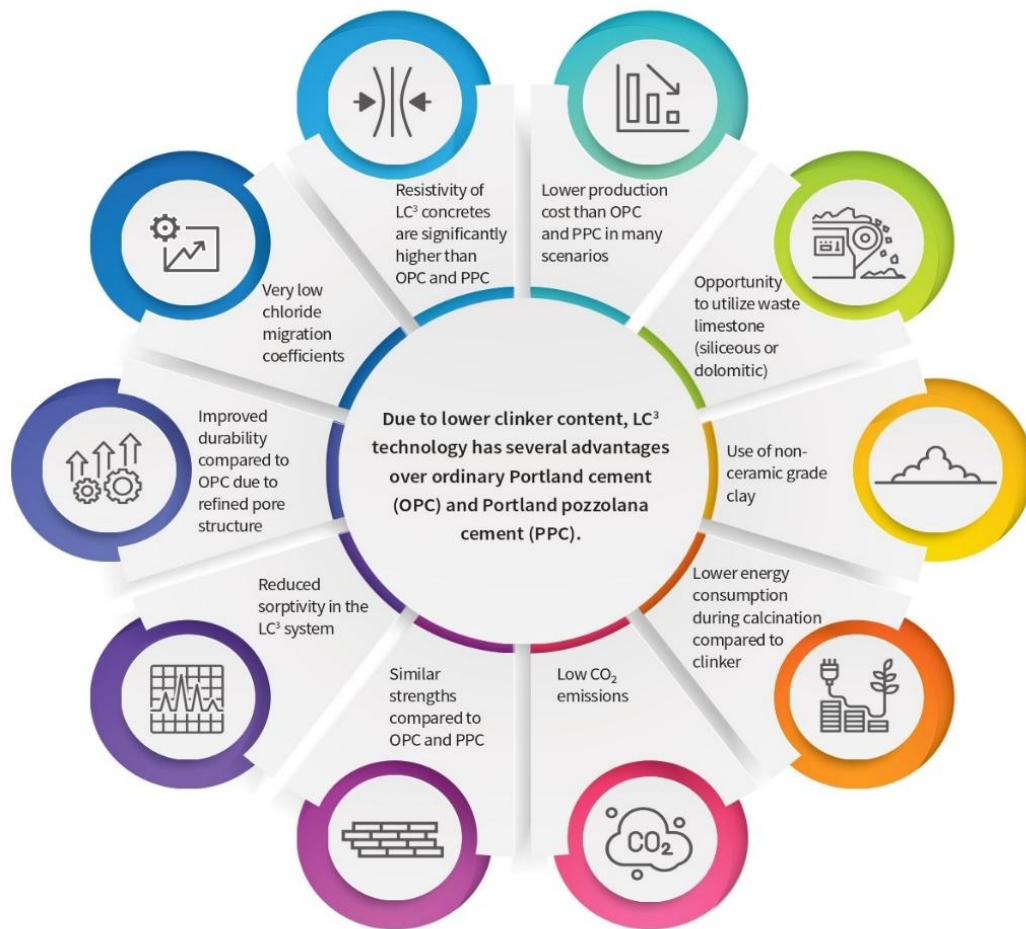


Fig.3. LC³ as an Advanced Alternative to OPC (<https://taratarc.com/technology>).

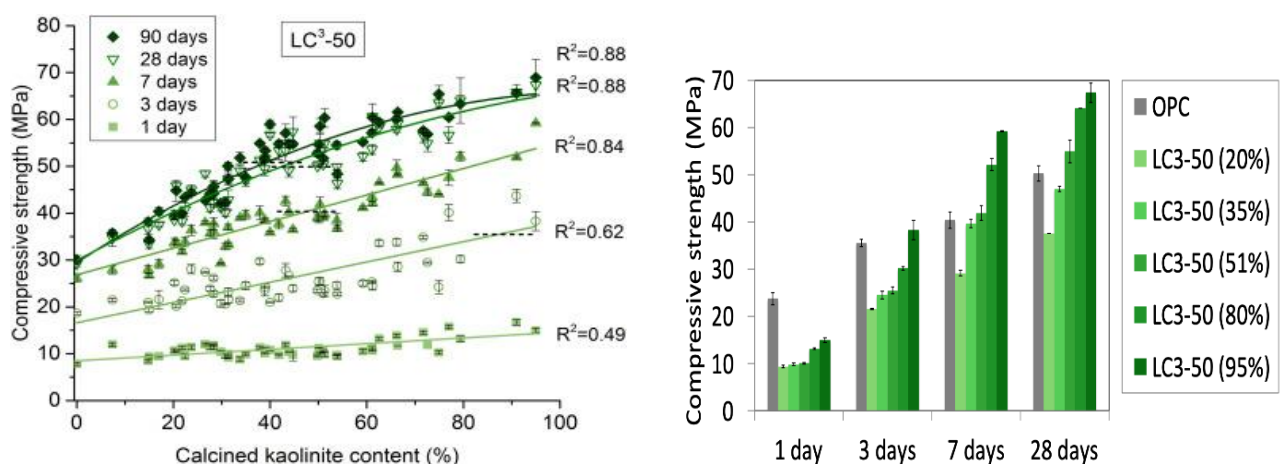


Fig. 4 - The relationship between compressive strength and the proportion of calcined kaolinite in LC³-50 [21].

All evaluations were conducted within the first 72 hours of the hydration process. A comparative analysis between kaolinite and montmorillonite clays revealed significant differences in the mechanisms underlying sulfate balancing in LC³ systems. The findings highlighted that the chemical interactions of the clays play a crucial role in achieving an optimal sulfate balance. Notably, the study emphasized that alternative clays, such as bentonites rich in montmorillonite, can effectively

address challenges associated with the rapid depletion of sulfates in LC3 formulations. This suggests that these alternative materials can serve as viable substitutes for metakaolin, providing a pathway to mitigate sulfate imbalance issues and improve the performance of LC3 mixes.

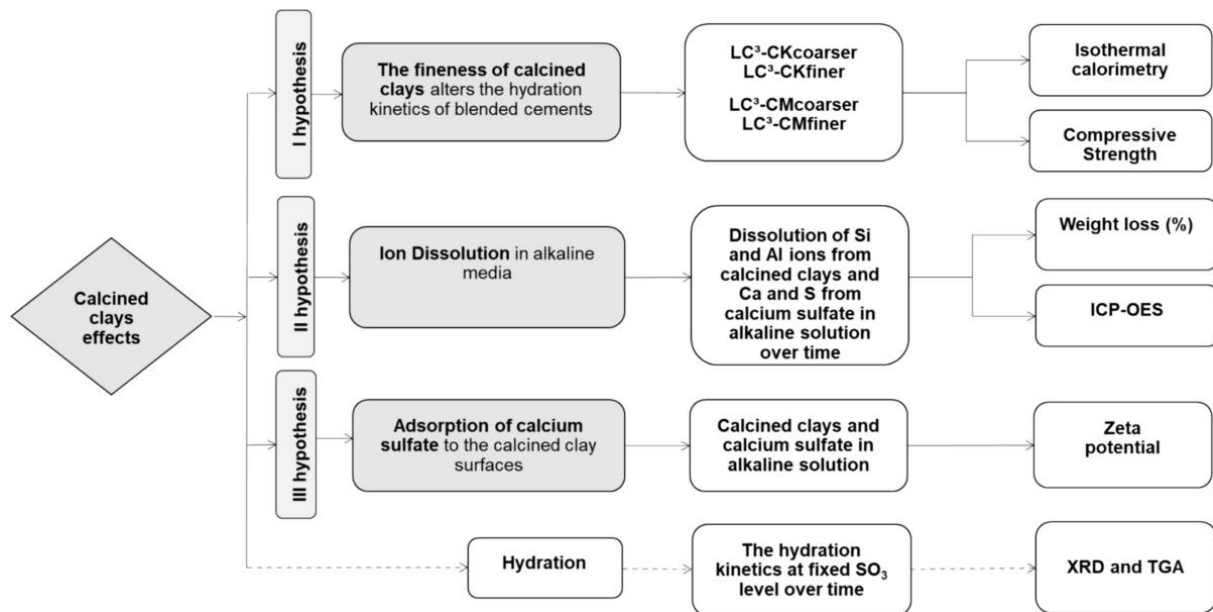


Fig. 5 - Physicochemical Influence of Kaolinite and Montmorillonite on LC3 Cement Hydration and Sulfate Balance [22].

2.2 Research gap and future study

a. Material Availability

The availability and quality of calcined clays for LC3 differ across regions. Research on alternative clay sources, such as kaolinite-rich industrial by-products or naturally occurring materials, is limited, and their performance requires further investigation. Efforts are needed to optimize calcination conditions for unconventional clays and evaluate their reactivity. Additionally, the influence of impurities such as quartz, iron oxides, and organic content on LC3 performance is not well understood.

b. Durability and mechanical Performance

LC3 has demonstrated encouraging outcomes in laboratory experiments, there is a lack of extensive field performance data across diverse environmental conditions, such as extreme climates and marine exposure. Further studies are required to examine LC3's durability in harsh environments, including resistance to sulfate attack, chloride ingress, and carbonation. Additionally, the long-term microstructural changes in LC3 remain insufficiently explored. The interactions among calcined clay, limestone, and cement clinker in LC3 systems are complicated. Further investigation is needed to identify suitable proportions for various applications. The impact of incorporating other mineral additives or supplementary cementitious materials, such as fly ash or slag, on LC3 properties requires deeper exploration. Challenges remain in understanding the water demand, flow behaviour, and workability of specific LC3 formulations. The mechanical characteristics of LC3, including tensile strength, creep, and shrinkage, need further study to support its use in structural applications. There is limited research on the performance of reinforced concrete made with LC3 under load-bearing conditions. Additionally, the effect of LC3 on the adhesion between reinforcing steel and concrete has not been extensively analyzed.

c. Standards and Certifications

Extensive research efforts are required to establish standards and certification protocols for LC3 concrete to facilitate its widespread adoption in the construction industry. Developing these standards will ensure consistency, reliability, and quality in the production and use of LC3 materials. Additionally, studies must

explore the economic feasibility of large-scale production and implementation, including cost-benefit analyses and supply chain considerations, to ensure the material is both affordable and accessible. Investigating user feedback and acceptance is crucial for identifying barriers to the adoption of LC3. Understanding concerns from stakeholders such as architects, engineers, and construction workers can help in designing targeted strategies to promote its use.

d. **Environmental and Economic Considerations**

Comprehensive life-cycle assessments are necessary to evaluate the overall environmental impact of LC3 compared to traditional concrete. These assessments should include factors such as carbon emissions, resource consumption, and potential waste reduction across the entire production and usage cycle. Optimizing the production process is another key area of research, particularly with a focus on reducing the energy requirements for calcination and improving the efficiency of manufacturing techniques. Additionally, studies should examine the performance of LC3 under diverse environmental and climatic conditions, assessing its adaptability and reliability in different regions. Long-term investigations into the durability of LC3 are also essential to determine its resistance to various environmental factors such as moisture, temperature fluctuations, and chemical exposure. Collectively, these research efforts will pave the way for the successful integration of LC3 into the construction industry. Research on enhancing calcination technologies to improve energy efficiency and minimize emissions during calcined clay production remains limited. The feasibility of incorporating renewable energy sources into the calcination process at an industrial scale requires further investigation. Additionally, a deeper understanding of how LC3 interacts with chemical admixtures, including superplasticizers, retarders, and accelerators, is needed. Adapting admixture formulations to accommodate the unique chemical composition of LC3, compared to Ordinary Portland Cement (OPC), presents specific challenges.

2.3 Areas for Further Research and Development

Explore the potential of combining LC3 with other low-carbon binders such as alkali-activated materials, geopolymers, or magnesium-based cements to further decrease carbon emissions. Investigate hybrid solutions that could offer specialized properties such as enhanced durability or accelerated setting times. Conduct large-scale field studies in various geographic areas to verify laboratory findings and monitor the long-term performance of LC3-based structures in real-world conditions. Leverage machine learning and advanced modeling techniques to predict LC3 behaviour based on raw material characteristics and processing parameters. Implement data-driven methods for optimizing mix designs and controlling calcination and grinding processes. Assess the viability of LC3 for 3D printing applications within the construction industry, focusing on its rheological and setting behaviour for digital fabrication. Pursue research aimed at reducing the energy requirements of LC3 production while maintaining performance standards. Test new kiln technologies or alternative calcination methods to improve efficiency. Investigate strategies to scale LC3 production and reduce costs, making it more viable for widespread use. Lastly, analyze potential policy incentives, financing models, and support mechanisms that could encourage LC3 adoption in developing countries. Following key points are essential to carryout the future research in the development of LC3.

1. potential challenges and its limitations.
2. Material availability and mix design.
3. Environmental health and economic factors.
4. Industrial Scale-up and process incorporation.
5. Durability, and long term performance.

3 Conclusion

- LC3 holds immense promise for transforming the construction industry, but unlocking its full potential demands practical strategies and collaborative innovation.

- LC3 emerges as a transformative alternative to conventional cement, combining environmental advantages, cost efficiency, and enhanced durability. Recent years have seen groundbreaking research exploring its viability as a sustainable building material, with pivotal discoveries poised to reshape its role in the construction industry.
- LC3 has remarkable ability to cut CO₂ emissions by up to 40%, attributed to its reduced clinker content and incorporation of calcined clay. This breakthrough positions LC3 as a pivotal solution for mitigating the environmental footprint of the construction sector, a major contributor to global CO₂ emission.
- LC3 has the similar strength and durability as a conventional cement, but it also offers a distinct advantage in terms of production cost, which is lower than that of traditional cement. This cost reduction stems from the use of abundant, lower-cost materials such as limestone and calcined clay, making it an economically viable alternative. LC3 has the capacity to replace up to 50% of the cement content in concrete without compromising its structural integrity or longevity, which depends on the mix design and context. This presenting a promising shift toward more sustainable building practices. Its adoption could drastically reduce both the environmental and financial costs associated with traditional cement, thereby reshaping the landscape of construction materials and furthering the industry's shift towards sustainability

REFERENCES

- [1]- Y. Dhandapani, M. Santhanam, R. Gettu, R. Pillai, Perspectives on Blended Cementitious Systems with Calcined Clay-Limestone Combination for Sustainable Low Carbon Cement Transition. *Ind. Concr. J.* 94 (2020) 31-45.
- [2]- S. Barbhuiya, J. Nepal, B.B. Das, Properties, compatibility, environmental benefits and future directions of limestone calcined clay cement (LC3) concrete: A review. *J. Build. Eng.* 79 (2023) 107794. <https://doi.org/10.1016/j.jobbe.2023.107794>
- [3]- K. Scrivener, F. Martirena, S. Bishnoi, S. Maity, Calcined clay limestone cements (LC3). *Cem. Concr. Res.* 114 (2018) 49-56. <https://doi.org/10.1016/j.cemconres.2017.08.017>
- [4]- F. Avet, E. Boehm-Courjault, K. Scrivener, Investigation of C-A-S-H composition, morphology and density in Limestone Calcined Clay Cement (LC3). *Cem. Concr. Res.* 115 (2019) 70-79. <https://doi.org/10.1016/j.cemconres.2018.10.011>
- [5]- M. Sharma, S. Bishnoi, F. Martirena, K. Scrivener, Limestone calcined clay cement and concrete: A state-of-the-art review. *Cem. Concr. Res.* 149 (2021) 106564. <https://doi.org/10.1016/j.cemconres.2021.106564>
- [6]- H. Shoukry, P. Perumal, A. Abadel, H. Alghamdi, M. Alamri, H.A. Abdel-Gawwad, Performance of limestone-calcined clay cement mortar incorporating high volume ferrochrome waste slag aggregate. *Constr. Build. Mater.* 350 (2022) 128928. <https://doi.org/10.1016/j.conbuildmat.2022.128928>
- [7]- F. Avet, K. Scrivener, Influence of pH on the chloride binding capacity of Limestone Calcined Clay Cements (LC3). *Cem. Concr. Res.* 131 (2020) 106031. <https://doi.org/10.1016/j.cemconres.2020.106031>
- [8]- A.M.S. Hassan, H. Shoukry, P. Perumal, M.M. Abd El-razik, R.M.H. Aly, A.M.Y. Alzahrani, Evaluation of the thermo-physical, mechanical, and fire resistance performances of limestone calcined clay cement (LC3)-based lightweight rendering mortars. *J. Build. Eng.* 71 (2023) 106495. <https://doi.org/10.1016/j.jobbe.2023.106495>
- [9]- A. Sharma, A.B.D. Roy, P.P. Bansal, Post-heating evaluation of fibre reinforced concrete with LC3 binder as replacement to OPC. *Constr. Build. Mater.* 407 (2023) 133603. <https://doi.org/10.1016/j.conbuildmat.2023.133603>
- [10]- N. Parsompech, R. Rianyo, A. Chaipanich, Compressive strength, water absorption and pulse velocity tests of calcined clay- limestone cement mortars. *Mater. Today: Proc.* 65 (2022) 2394–2398. <https://doi.org/10.1016/j.matpr.2022.05.526>
- [11]- T.F. Awolusi, A.O. Sojobi, D.O. Oguntayo, O.O. Akinkurolere, B.O. Orogade, Effects of calcined clay, sawdust ash and chemical admixtures on Strength and Properties of concrete for pavement and flooring applications using Taguchi approach. *Case Stud. Constr. Mater.* 15 (2021) e00568. <https://doi.org/10.1016/j.cscm.2021.e00568>
- [12]- V. Shah, A. Parashar, G. Mishra, S. Medepalli, S. Krishnan, S. Bishnoi, Influence of cement replacement by limestone calcined clay pozzolan on the engineering properties of mortar and concrete. *Adv. Cem. Res.* 32(3) (2020) 101-111. <https://doi.org/10.1680/jadcr.18.00073>
- [13]- J. Liu, W. Zhang, Z. Li, H. Jin, W. Liu, L. Tang, Investigation of using limestone calcined clay cement (LC3) in engineered cementitious composites: The effect of propylene fibers and the curing system. *J. Mater. Res. Technol.* 15 (2021) 2117-2144. <https://doi.org/10.1016/j.jmrt.2021.09.023>

-
- [14]- S. Wali, S. Saxena, M. Kumar, S. Maity, S. Bishnoi, Application of Industrially Produced LC3 to Pavements, AAC Blocks and Other Products. In: Martirena, F., Favier, A., Scrivener, K. (eds) *Calcined Clays for Sustainable Concrete*. RILEM Bookser. 16 (2018) 482-487. https://doi.org/10.1007/978-94-024-1207-9_77
- [15]- H. Alghamdi, H. Shoukry, A.A. Abadel, M. Khawaji, Performance assessment of limestone calcined clay cement (LC3)-Based lightweight green mortars incorporating recycled waste aggregate. *J. Mater. Res. Technol.* 23 (2023) 2065-2074. <https://doi.org/10.1016/j.jmrt.2023.01.133>
- [16]- S.S. Reddy, M.A.K. Reddy, Lime calcined clay cement (lc3): a review. *IOP Conf. Ser.: Earth Environ. Sci.* 796 (2021) 012037. <https://doi.org/10.1088/1755-1315/796/1/012037>
- [17]- M. Abdulqader, H.R. Khalid, M. Ibrahim, S.K. Adekunle, M.A. Al-Osta, S. Ahmad, M. Sajid, Physicochemical properties of limestone calcined clay cement (LC3) concrete made using Saudi clays. *J. Mater. Res. Technol.* 25 (2023) 2769-2783. <https://doi.org/10.1016/j.jmrt.2023.06.114>
- [18]- A. Marani, L. Zhang, M.L. Nehdi, LC3 with microencapsulated phase change materials for reducing embodied and operational carbon. *Cem. Concr. Res.* 172 (2023) 107234. <https://doi.org/10.1016/j.cemconres.2023.107234>
- [19]- N. Ijaz, W. Ye, Z. Rehman, Z. Ijaz, M.F. Junaid, Global insights into micro-macro mechanisms and environmental implications of limestone calcined clay cement (LC3) for sustainable construction applications. *Sci. Total Environ.* 907 (2024) 167794. <https://doi.org/10.1016/j.scitotenv.2023.167794>
- [20]- F. Avet, R. Snellings, A.A. Diaz, M.B. Haha, K. Scrivener, Development of a new rapid, relevant and reliable (R3) test method to evaluate the pozzolanic reactivity of calcined kaolinitic clays. *Cem. Concr. Res.* 85 (2016) 1-11. <https://doi.org/10.1016/j.cemconres.2016.02.015>
- [21]- F. Avet, K. Scrivener, Investigation of the calcined kaolinite content on the hydration of Limestone Calcined Clay Cement (LC3). *Cem. Concr. Res.* 107 (2018) 124-135. <https://doi.org/10.1016/j.cemconres.2018.02.016>
- [22]- M.R.C. Da Silva, J.S. Andrade Neto, B. Walkley, Effects of kaolinite and montmorillonite calcined clays on the sulfate balance, early hydration, and artificial pore solution of limestone calcined clay cements (LC3). *Mater. Struct.* 57 (2024) 187. <https://doi.org/10.1617/s11527-024-02462-3>