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Comprehensive Analysis of Lime-Cement Concrete (LCC) Materials: Properties, Methods, and Applications

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Lime-cement concrete (LCC) is a type of building construction material that is made by mixing lime and cement with aggregates (like sand or gravel) and water. The existing research on lime-cement concrete's structural characteristics lies in the limited understanding of its long-term durability, microstructural evolution under various environmental conditions, and its performance in modern construction. This study analyses the structural properties of lime-cement concrete, a composite material incorporating lime and cement to enhance the durability and sustainability of concrete structures, by analyzing the mechanical properties such as elasticity modulus, compressive strength, and flexural strength at varying contents of lime and cement. Several methods are used to determine the properties of LCC such as compressive strength, flexural strength, tensile strength, water permeability, modulus of elasticity, thermal conductivity, and Poisson ratio. The result shows that the characteristics of Hydraulic LCC, highlighting its compressive strength (45.5 MPa), flexural strength (3 MPa), tensile strength (4.11 MPa), water permeability (4.40×10^{-6} m/s), modulus of elasticity (28,992 MPa), thermal conductivity (0.3 W/m·K) and Poisson ratio (0.1-0.2), and other properties like setting time, water absorption, density, shrinkage, porosity, and carbonation rate. Hydraulic LCC's moderate strength and flexibility make it suitable for masonry, restoration work, and eco-friendly construction. The study findings suggest that reducing the total cement content will reduce environmental impact as they are directly linked. It contributes to the continued development of sustainable building materials and provides essential information that can be useful in civil engineering projects that require improved performance and sustainability.

Keywords: Calcium Carbonate, Compressive Strength, Hydraulic, Lime Cement Concrete, Portland Cement.

1. Introduction

The term "concrete" refers to any artificially made mixture of cement, sand, aggregates, and water that is used to harden stone, either with or without the proper admixture. Beams, columns, blocks, and other structural parts are made of concrete. In contrast, mortar is a concoction of water, sand, as well as cement that is used to create concrete masonry units, plaster walls, and bind bricks or stones during wall construction (Jahandari et al., 2019; Sugawara & Nikaido, 2014). Although the primary component of mortar and concrete is cement, small amounts of other substances, such as glass, silica fume, fly ash, red mud, as well as hydraulic lime, can be incorporated into cement to enhance its mechanical qualities. Shear bonding strength, flexural strength, tensile strength, and compressive strength are a few of them. Lime is the main binder in a variety of combinations, such as hydraulic lime or limestone putty. For thousands of years, lime has also been widely used in several construction operations where it is considered a strong abundant, and versatile binder like lime mortar and concrete. Calcium, an inorganic substance that is found naturally and is mostly composed of carbonates, oxides, and hydroxides, is the element that is mostly present in lime. Chalk or limestone is used to construct it. Crushing, cutting, or grinding particles down may cause a chemical transformation. Lime increases the water content and air content while enhancing workability plasticity cohesiveness or adhesion (Mani Kandhan & Karunakaran, 2021).

The remarkable properties of lime have made it a versatile material for construction since antiquity. Lime is tough enough to support the strains imposed upon buildings without failing, durable enough to last for decades, and allows for some flexibility in case of displacement. Also, its porosity allows for evaporation of steam from the inside thus reducing chances of mold formation and moisture accumulation. For centuries, lime has been used as plaster and mortar in all parts of the world (Vilcekova et al., 2023; Wöhrmeyer & Parr, 2008). The precise date when lime was first used in construction is not known. However, it is established that the Roman Empire widely used mortar that contained lime. Limestone, a sedimentary rock that is mostly composed of calcium carbonate, is heated in a kiln during the lime-making process to create quicklime, also known as calcium oxide (Ercan & Özbek, 2021). To make hydrated lime, also referred to as calcium hydroxide, the next step is the slaking or mixing with water of quicklime. The uses of lime in buildings are many including rendering, plastering, and preparing mortar. In addition, it can serve as a binder in concrete as well as stabilizing soil. Limestone, a sedimentary rock that is mostly composed of calcium carbonate, is heated in a kiln during the lime-making process to create quicklime, also known as calcium oxide (Taylor, 2019). One of the most significant and often used building materials is concrete. According to conventional definitions, for example, it is a composite material mostly made up of cement, water, and fine and coarse aggregates mixed in predetermined proportions. Plain concrete is cement, sand, and stones but in principle, it holds together through a binding agent usually in present-day forms of powdered mineral substance known as ‘cement’. With such high volumes release around 1. 4 billion tons per annum or so about 6% of all anthropogenetic emissions global climate management plan (Afsah, 2004).

2. Objectives

The study aims to explore the structural properties of LCC, relating to its mechanics, durability, and performance under various conditions. It will consider compressive strength, ductility, and resistance to other stresses to determine how well LCC performs. Ultimately it will lead to finding ways to improve the design, application, and durability of lime-cement concrete in construction activities.

This study carries out a comparative analysis of the structural characteristics of types of lime cement concrete based on different properties and parameters. Section 1 described the lime as an essential component of building materials used by the Greeks, Romans, and Egyptians. The review of literature is presented in section 2 to provide an earlier study in the context of structure using environmentally friendly concrete made from hydrated lime and rice husk ash. The material and methods are present in section 3 to analyze types of lime-cement concrete structural characteristics based on the different parameters. The results discussion and conclusion are presented in sections 4 and 5.

3. Literature Review

F. M. Mazzolani et al. (Costigan et al., 2009) discussed the strength behavior of lime mortars in clay brick masonry bonds, both hydraulic as well as non-hydraulic. Both vertical and lateral loads were applied to two different kinds of masonry. According to the authors' findings, Natural Hydraulic Lime (NHL5) mortar's flexural bond strength improves by 80% while its compression and flexural strengths improve by 60–65% between 28 and 56 days. Though the NHL5 bound masonry's compressible strength only rises 11%, after 56 days of use, the NHL 5 mortar outperforms the NHL 5 masonry in terms of compression, while the CL90-s mortar and masonry exhibit a negative trend.

A. O. Olujide (Olujide, 2017) examined the concrete's tensile and flexural strengths made with hydrated lime cement. Cement was utilized instead of hydrated lime in this investigation, ranging from 5% to 30%. According to the authors, after 28 days of hardening, cement substituting 13.83% hydrated lime exhibited the largest flexural capacity and tension qualities; the former was greater than the latter.

S. S. Kumar (Kumar, 2018) conducted experiments on concrete's split tensile, flexural, and compressive strengths. They replaced the cement in the concrete with powdered lime and the fine aggregates with groundnut shells. The groundnut shell small aggregate was substituted with lime powder in a general proportion of 20 percent, whereas the groundnut shell fine aggregate was altered in percentages 5, 10, 15, and 20 in this study. They concluded that lime concrete gets more strength at 20% and groundnut shell concrete at 5% to 10% more power than regular concrete.

S. Pavía and R. Hanley (Pavía & Hanley, 2010) investigated mortar's (NHL) flexural bond strength concerning the mortar's hydraulicity, volume of water, workability, as well as water retention. The NHL5 mortar was found to have the best workability, strongest bond, combined moderate flow, and greatest ability to absorb water all at once. Despite achieving lower bond strengths with ideal workability, NHL 2 and NHL 3.5 mortars have the strongest bond if compared to other mortars having the highest flow values.

P. A. Adesina and F. A. Olutoge (Adesina & Olutoge, 2019) investigated how Rice Husk ash (RHA) and lime could be mixed and used in varying proportions in place of regular cement, producing RHA-lime concrete. According to the strength test results, RHA-Lime concrete demonstrated better initial strength than the control. However, lime leaching hindered the initial growth of strength. It was also shown that RHA-Lime cement mixes may substitute conventional cement by up to 25% in structural concrete. The pozzolanic reaction was accelerated by the addition of lime, which is why RHA-Concrete has its strength characteristics. For this reason, RHA-Lime mixes may be used as a good substitute for ordinary cement in concrete.

X. Qian et al. (Qian et al., 2019) aim of that research was to enhance the efficiency of cement mortar by using the synergistic effect between calcium carbonate with metakaolin with cement through the proposed pre-carbonation process. According to the author, in this on-site method, carbon dioxide bubbles are used to form calcium carbonate particles in the slaked lime slurry, with sizes ranging from nano to sub-micron. After that, the produced carbonated slurry is mixed with additional mortar materials. Tests indicate that the suggested technique enhances the mechanical properties and longevity of the blended metakaolin mortar. Because calcium carbonate ions provide more heterogeneous nucleation sites, calorimetry results indicate that the consumption of carbonated slaked lime slurry leads to denser microstructures for mortar and concrete, as the amount of hydration product increases. All these results point to a practical solution of using calcium carbonate nanoparticles of nano to sub-micro size to enhance the performance characteristics of metakaolin blended type of cement when synthesized on site.

F. Zunino et al. (Zunino et al., 2020) explore the effects of calcite impurities on the reactivity and mineralogy of kaolinitic clay. Different proportions of calcite were mixed with the kaolin sample. The results indicate that although calcite breaks down during calcination, no appreciable amount of free lime or amorphous calcium carbonate is generated. The kaolinite particles were found to be partially covered by sandy mass. The breakdown of calcite and the formation of this mass is related to the reduction in the specific surface area which increases with the increase in the mixing of calcite in the raw clay. This deposit is a new phase that arises from the interaction of kaolinite and calcite, with Al/Si ratios ranging from 0.74 to 0.88 and Ca/Si ratios between 0.86 and 1.65 as investigated using “Transmission Electron Microscopy Energy-Dispersive X-ray Spectroscopy” (TEM-EDS). Both the breakdown of calcite and its detrimental effect on reactivity can be minimized by lowering the calcination temperature to 700 °C.

J. Pooni et al. (Pooni et al., 2020) experimented with the primary hydration products and microstructural characteristics related to the amount and cure rate of Calcium Sulfoaluminate (CSA) cement have been identified, allowing research to explore stabilization techniques for expansive clays treated with CSA. The findings indicate that three major processes including cationic exchange, flocculation, and agglomeration between mineral soil layers promote changes in the mechanical properties and microstructural aspects of CSA cement upon the addition of cementitious dehydrating substances. Studies show that the use of CSA cement during soil stabilization reduces the carbon footprint associated with conventional stabilization techniques, thereby promoting environmentally friendly processes.

4. Methods and Materials

Due to its flexibility and strength, concrete is the most common building material around the world. It is important for numerous structural and non-structural functions. Concrete that will support structures has to be very strong while non-structural types like LCC may allow small reductions in strength without affecting their functionality at all.

Lime-cement mortar is a type of mortar that combines lime with cement for improved characteristics. It is made of sand, water, and binding agents such as cement or lime. Based on the binding agent used, this kind of mortar can be classified into three categories namely cement mortar (which contains cement), lime mortar (made of lime), and lime-cement mortar (which has both). Compared to traditional lime mortars, lime-cement mortar has more strength and durability. Moreover, according to some sources, surkhi which refers to a finely powdered form of burnt clay may be added to increase tensile strength and improve upon longevity.

LCC contains hydraulic lime which used to be among the essential cements before the modern-day use of the Portland cement. In contrast with non-hydraulic limes, hydraulic lines are set through reactions with water which makes them appropriate when there needs to be resistance against moisture. It includes such components as calcium silicates together with calcium hydroxide which are responsible for keeping a balance between the qualities offered by Portland Cement on one hand and those obtained from conventional lime on the other. Due to its quick curing time and enhanced strength properties, hydraulic LCC serves well as a foundation material even for underwater structures or areas that are constantly wet.

Pure lime is the base of non-hydraulic LCC and it hardens through carbonation (the reaction with carbon dioxide from air). This lime concrete is applied where high strength is not needed, for example, it's used in historical restorations. Compared with hydraulic LCC it has lower compressive, tensile, and flexural strength but has high water vapor permeability and breathability.

Pozzolanic LCC is the modern method used in lime concrete. The low-carbon and environmentally friendly alternative to Portland cement is made by mixing hydrated lime with pozzolanic materials like volcanic ash. Its compressive strength is no different from that of traditional Portland cement but has lower embodied carbon thus making it much more sustainable as opposed to Portland cement. Besides, it is also easier to handle during construction processes, as well as more versatile since it can be used both for structuring purposes and other decorative aspects.

An innovative material is limecrete or lime-cement lightweight concrete. It is made by mixing lime with sand or lightweight aggregates, and this results in concrete that is flexible and breathable as well as having lower environmental impact. Limecrete's moisture control property makes it especially valuable in conserving historic buildings and promoting green architecture due to its minimal carbon emissions. Furthermore, it weighs much less than regular concrete hence reducing the stress on structures. The process of Lime Stabilised Soil Concrete entails the blending of lime with soil, to enhance the properties of the latter. Thus, it increases soil strength, decreases shrinkage and swelling, as well as enhancing resistance to freeze-thaw cycles. Most commonly used for low-cost and environmentally friendly solutions are lime-stabilized soils for road works, parking spaces, or constructions.

Several methods are used for determining the properties of LCC such as compressive strength, flexural strength, tensile strength, modulus of elasticity, thermal conductivity, water permeability, and Poisson ratio.

4.1 Compressive Strength

The formula to compute the compressive strength of materials like concrete is given as follows in Equation 1:

Compressive Strength (f_c)=P/A Eq. (1)

Where:

P = load applied to the specimen (in Newtons or pounds).

A = cross-sectional area of the specimen (in square meters or square inches).

For concrete, the compressive strength is often reported in units of megapascals (MPa) or pounds per square inch (psi) in Table 1.

Table 1: Represent the value of P, A, and Fc.

Sr. No.	Load (P)	Area (A)	Compressive Strength (f_c)	LLC
1	100 kN	50 cm²	20 MPa	Lime-Cement Mortar
2	500 kN	110 cm²	45.5 MPa	Hydraulic LCC
3	200 kN	80 cm²	25 MPa	Non-Hydraulic LCC
4	300 kN	75 cm²	40 MPa	Pozzolanic LCC
5	700 kN	180 cm²	38.8 MPa	Limecrete (Lime-Cement Lightweight Concrete)
6	250 kN	210 cm²	19.1 MPa	lime-stabilized soil concrete

Here’s how you calculate it:

For a load of 100 kN and an area of 50 cm²:

Convert area to m²: 50 cm² = 0.005 m²

$$\text{Compressive Strength } (f_c) = \frac{P}{A} = \frac{100\text{kN}}{0.005\text{m}^2} = 20\text{MPa}$$

4.2 Flexural Strength

The flexural strength of cement concrete has a certain formula lying at its basis, which serves as an approximation for the modulus of rupture. In simpler terms, this means that bending is being used in this case to find out how strong is concrete under tension in Equation 2. In short, this is the formula applicable to all types of concrete including Lime-Cement in Table 2:

$$f_r = \frac{P.L}{bd^2} \qquad \text{Eq. (2)}$$

Where:

F_r = Flexural strength (Modulus of Rupture) in MPa (or psi)

P = Maximum load applied to the specimen in Newtons (or pounds-force)

L = Length of the span between the supports in millimeters (or inches)

b = Width of the specimen in millimeters (or inches)

d = Depth (height) of the specimen in millimeters (or inches)

Let's assume the units are in millimeters for L, b, and d, and Newtons for P.

Table 2: Represent the value of P, L, b, d, and F_r.

Sr. No.	P (N)	L (mm)	b (mm)	d (mm)	Fr (MPa)	LLC
1	2000	600	100	100	1.333	Lime-Cement Mortar
2	5000	600	100	100	3	Hydraulic LCC
3	3000	600	100	100	1.8	Non-Hydraulic LCC
4	4000	600	100	100	2.667	Pozzolanic LCC
5	2000	800	100	100	1.6	Limecrete (Lime-Cement Lightweight Concrete)
6	2000	600	150	100	0.8	lime-stabilized soil concrete

Here's how to calculate Fr = $\frac{P.L}{bd^2}$

For P= 2000 N, L= 600 mm, b=100 mm, d=100 mm:

$$F_r = \frac{2000 * 600}{100 * 100^2} = 1.333 \text{ MPa}$$

3.3 Tensile Strength

Tensile strength for cement concrete can be determined using empirical formulas that relate tensile strength to compressive strength in Table 3. Although the precise formula can vary depending on the specific mixture and testing method, a commonly used relationship for estimating the tensile strength (f_t) from the compressive strength (f_c) in concrete Equation 3:

$$f_t = k * \sqrt{f_c} \qquad \text{Eq. (3)}$$

Where:

f_t= tensile strength

f_c = compressive strength

k = coefficient that varies depending on the type of concrete and testing method.

The k coefficient in lime-cement concrete can be in a range of 0.50 to 0.75 based on the mix proportions, curing conditions, and the content of lime.

Table 3: Represent the value of F_c, k, and F_t.

Sr. No.	Fc (MPa)	k	Ft (MPa)	LLC
1	10	0.50	1.58	Lime-Cement Mortar
2	30	0.75	4.11	Hydraulic LCC
3	20	0.50	2.24	Non-Hydraulic LCC
4	20	0.75	3.35	Pozzolanic LCC
5	30	0.50	2.74	Limecrete (Lime-Cement Lightweight Concrete)

6	10	0.75	2.37	lime-stabilized soil concrete

f_t is the tensile strength in MPa, calculated using the formula, $f_t = k * \sqrt{f_c}$

$f_t = 0.5 * \sqrt{10}$ =1.58

3.3.1 Modulus of Elasticity

Cement concrete's modulus of elasticity Ec can be calculated by using some formulas that are based on the compression strength of the material and mix ratios in Table 4. For instance, one general way to do it is to modify the expression for normal concrete in Equation 4:

$$E_c = k * f_c^{1/2} \quad \text{Eq. (4)}$$

Ec = modulus of elasticity in MPa (or psi).

f_c = compressive strength of the concrete in MPa.

k = constant that is dependent on the composition of the concrete; for concrete in MPa units, it usually ranges from 4,000 to 5,000.

Table 4: Represent the value of f_c, k, and E_c.

Sr. No.	f_c (MPa)	k	E_c (MPa)	LLC
1	20	3600	16,100	Lime-Cement Mortar
2	50	4100	28,992	Hydraulic LCC
3	30	3300	18,075	Non-Hydraulic LCC
4	35	3800	22,482	Pozzolanic LCC
5	40	3200	20,240	Limecrete (Lime-Cement Lightweight Concrete)
6	25	4400	22,000	lime-stabilized soil concrete

Ec is the modulus of elasticity, calculated as $E_c = k * f_c^{\frac{1}{2}}$

E_c=3600*$\sqrt{20}$=16,100.

3.4 Thermal Conductivity

In general, thermal conductivity for any material such as Lime-Cement Concrete is represented using this formula in Equation 5:

$$k = \frac{QL}{A\Delta Tt} \quad \text{Eq. (5)}$$

k = Thermal conductivity (W/m·K),

Q = amount of heat transferred (Joules),

L = thickness of the material (meters),

A = cross-sectional area perpendicular to the heat flow (square meters),

ΔT = temperature difference across the material (Kelvin or Celsius),

t = time over which the heat transfer occurs (seconds).

Concerning LCC, its thermal conductivity may additionally be seen in different empirical forms or materials that depend on the proportion of lime and cement, the moisture content, and the type of aggregates used in Table 5.

Table 5: Represent the variables k, Q, L, A, Δ, and t.

Sr. No.	Thermal Conductivity k (W/m·K)	Heat Transfer Q (Joules)	Thickness L (meters)	Area A (m^2)	Temperature Difference ΔT (K)	Time t (seconds)	LLC
1	0.03	7000	0.15	2.5	25	500	Lime-Cement Mortar
2	0.3	5000	0.1	2.0	20	400	Hydraulic LCC
3	0.05	4500	0.08	1.5	15	350	Non-Hydraulic LCC
4	0.04	6000	0.12	2.2	18	450	Pozzolanic LCC
5	0.02	8000	0.2	3.0	30	600	Limecrete (Lime-Cement Lightweight Concrete)
6	0.2	6500	0.4	3.5	12	300	lime-stabilized soil concrete

k is the thermal conductivity of LCC, calculated as $= \frac{QL}{A\Delta Tt}$

$k = \frac{5000*0.1}{2*2*400}$=0.3 W/m·K.

3.5 Water Permeability

Darcy's Law, commonly used to describe the flow of fluid through porous media, can be used to model the water permeability of LCC in Table 6. The general equation for water permeability k in Equation 6:

$$k = \frac{QL}{A\Delta H} \quad \text{Eq. (6)}$$

Where:

k = Coefficient of permeability (m/s)

Q = Flow rate of water through the concrete (m^3/s)

L = Length of the concrete sample (m)

A = Cross-sectional area of the concrete sample perpendicular to the flow (m^2)

ΔH = Hydraulic head difference across the concrete sample (m).

Table 6: Represent the value of k, Q, L, A, and ΔH.

Sr. No.	Flow Rate Q (m^3/s)	Length L (m)	Area A (m^2)	Hydraulic Head Difference ΔH (m)	Coefficient of Permeability k (m/s)	LLC
1	2.25×10^{-7}	0.2	0.03	0.5	3.0×10^{-6}	Lime-Cement Mortar
2	1.80×10^{-7}	0.22	0.02	0.45	4.40×10^{-6}	Hydraulic LCC

3	3.00×10^{-7}	0.15	0.04	0.6	1.88×10^{-6}	Non-Hydraulic LCC
4	1.50×10^{-7}	0.25	0.025	0.4	3.75×10^{-6}	Pozzolanic LCC
5	3.75×10^{-7}	0.18	0.05	0.7	1.93×10^{-6}	Limecrete (Lime-Cement Lightweight Concrete)
6	1.90×10^{-7}	0.25	0.04	0.49	2.42×10^{-6}	lime-stabilized soil concrete

The calculated values of the coefficient of permeability k for each set of parameters first are:

To calculate the water permeability of LCC is $k = \frac{QL}{A\Delta H}$

$$k = \frac{2.25 * 10^{-7} * 0.2}{0.03 * 0.5} = 3 * 10^{-6}$$

3.6 Poisson Ratio

LCC and many other concrete materials usually have Poisson's ratio ranging from 0.1 to 0.2. Poisson ratios for the various concrete mixtures were obtained to determine the values of the modulus of rigidity MOR of the concrete in Equation 7.

$$\mu = \frac{\delta_t}{\delta_c} \quad \text{Eq. (7)}$$

Where:

μ = Poisson's ratio

δ_c = compressive strength at cracking (N/mm^2)

δ_t = tensile stress at cracking in flexure (N/mm^2).

4. Results and Discussion

4.1. Properties Measured of Types of LCC by Different Methods

Lime cement concrete, which is a combination of lime as well as cement as binder materials is used in construction for various purposes. Lime enhances workability and breathability while cement provides strength.

4.1.1. Lime-Cement Mortar

Sand, water, and other binding substances are the ingredients of mortar. These binding agents might be cement, lime, etc. These components allow for the classification of mortar into several kinds. If cement is added to the mortar, it is referred to as cement mortar. They are also referred to as lime mortar or surkhi mortar, depending on whether lime or surkhi is used. It's called lime cement mortar if lime is used with cement to create the mortar. Compared to the other kinds of mortar, it has a few unique characteristics (Byjus, 2023). These characteristics improve the mortar's total strength and provide the building with more strength. Surkhi is sometimes added to lime mortar to increase its tensile strength and longevity. Lime, water, and surkhi are combined to make surkhi mortar. Burnt clay is the raw material used to make surkhi. It is combined in powdered form with lime mortar as seen in Table 7.

Table 7: Illustrates the characteristics of LC mortar.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	20	MPa (Mega-Pascals)
2	Flexural Strength	1.333	MPa
3	Tensile Strength	1.58	MPa
4	Water Permeability (k)	3.0×10^{-6}	(m/s)
5	Elastic Modulus	16,100	MPa
6	Thermal Conductivity	0.03	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

4.1.2. Hydraulic LCC

Except for conservation projects, hydraulic lime is hardly utilized these days despite being a significant cementitious ingredient before the arrival of Portland cement. Because of the decrease in the demand for hydraulic lime, there are fewer competent producers available, and those who do come up short sometimes have to start from scratch to acquire the necessary abilities (Action, n.d.). Producing high-quality hydraulic lime is as much a craft as a technology. In contrast to other varieties of lime that harden chemically via reactions with carbon dioxide in the atmosphere, hydraulic lime hardens in part through reactions with water. Despite being made similarly to regular lime, hydraulic lime possesses qualities that are halfway between those of Portland cement and regular lime. Hydraulic lime includes calcium silicates as well as calcium hydroxide, the chemical that constitutes regular lime. These silicates are comparable to the primary cementitious ingredients in Portland cement. The characteristics of Hydraulic LCC are in Table 8.

1) Raw Materials

Hydraulic lime is made from limestone that has a small amount of clay and calcium carbonate in it. This kind of limestone is called argillaceous. Between 15 and 35 percent silica and alumina, two significant clay components, are present in the majority of limestones used to produce hydraulic lime. Grey or blue-colored limestones make up the majority of argillaceous limestones. Their dull surface, which does not glitter in the sun when fractured, is another way to identify them. Whenever a few drops of diluted hydrochloric or sulfuric acid are applied to argillaceous limestones, they will fizz, just like any other variety of limestone. In some places, marlstone, a soft limestone, is a popular raw material used to make hydraulic lime.

Table 8: Illustrates the characteristics of Hydraulic LCC.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	45.5	MPa (Mega-Pascals)
2	Flexural Strength	3	MPa
3	Tensile Strength	4.11	MPa

4	water permeability	4.40×10^{-6}	(m/s)
5	Elastic Modulus	28,992	MPa
6	Thermal Conductivity	0.3	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

4.1.3 Non-Hydraulic LCC

When exposed to water, non-hydraulic lime does not solidify or harden. It is mostly made up of pure, highly calcium limestone with very few contaminants. This kind of lime hardens gradually by a process called carbonation, in which carbon dioxide from the atmosphere is taken up by the lime. The characteristics of Non-Hydraulic LCC are seen in Table 9.

Table 9: Illustrates the characteristics of Non-Hydraulic LCC.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	25	MPa (Mega-Pascals)
2	Flexural Strength	1.8	MPa
3	Tensile Strength	2.24	MPa
4	water permeability	1.88×10^{-6}	(m/s)
5	Elastic Modulus	18,075	MPa
6	Thermal Conductivity	0.05	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

4.1.4 Characteristics of Pozzolanic LCC

It is uncommon to discover that a newly popular material in the construction industry has its roots in a production process that is almost 9,000 years old. However, the UK branch of Danish engineering firm Ramboll is working on a novel building material that has the potential to be revolutionary. The goal of lime pozzolan concrete is to provide a low-carbon, more environmentally friendly substitute for Portland cement and other comparable traditional forms of reinforced concrete. It is based on an antiquated method of cement binding that creates hydraulically set concrete by mixing slaked lime with naturally existing pozzolanic elements, such as volcanic ash. This new type of concrete was created through a five-year doctoral research scheme. It has undergone extensive testing to assess its structural and decorative capabilities and dispel the myth that Portland-based cement alternatives set faster and are more resilient than lime-based building materials. As a result, the novel material exhibits a 28-day strength capacity of around 40MPa, which is comparable to Portland cement. However, it may also result in considerable carbon savings. 60–70% less embodied carbon was utilized in the development of a prototype polished lime pozzolan concrete floor throughout the study phase than in a normal Cement Type I (CEM1) concrete floor. The majority of precast and ready-mixed concrete uses Portland cement, and CEM1 is the most commonly used kind. The characteristics of Pozzolanic LCC are seen in Table 10.

Table 10: Illustrates the characteristics of Pozzolanic LCC.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	40	MPa (Mega-Pascals)
2	Flexural Strength	2.667	MPa
3	Tensile Strength	3.35	MPa
4	Water Permeability	3.75×10^{-6}	(m/s)
5	Elastic Modulus	22,482	MPa
6	Thermal Conductivity	0.04	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

4.1.5 Limecrete (Lime-Cement Lightweight Concrete)

An alternative to concrete called limecrete is made of sand or light aggregate mixed with naturally generated hydraulic lime. This results in a floor slab that is somewhat flexible and breathable. They never add cement to our limecrete since doing so would make it less breathable. Limecrete, known also as lime-cement lightweight concrete, is a building material in which lime or hydraulic time as a traditional binder combines with such modern additives as cement and lightweight aggregates. This blend gives the final concrete product higher flexural, permeable, and greener characteristics than regular concrete. Limecrete is widely adopted in the conservation of old buildings and other green architecture projects due to its moisture control, low carbon footprints, and improved insulation. It is also easier to handle because of the advantage of lighter weights hence it exerts less pressure or load on some constructions. The characteristics of LC Lightweight Concrete are seen in Table 11.

Table 11: Illustrates the characteristics of LC Lightweight Concrete.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	38.8	MPa (Mega-Pascals)
2	Flexural Strength	1.6	MPa
3	Tensile Strength	2.74	MPa
4	Water permeability	1.93×10^{-6}	(m/s)
5	Elastic Modulus	20,240	MPa
6	Thermal Conductivity	0.02	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

Limecrete has the desirable characteristics of being friendly to the environment, vapor permeable, and appropriate for use in structures that are conservation-sensitive. However, since it possesses low strength compared to normal concrete, it is typically applied where these properties are of greater significance than concrete compressive strength.

4.1.6 Characteristics of Lime-Stabilized Soil Concrete

The method of stabilizing soil involves mixing cement or lime into the soil to alter its physical and chemical properties and increase its long-term strength. Soil stabilization builds on soil alteration by enhancing the properties of the soil. According to a 2017 Long-Term Resistance to Chloride (LTRC) study that evaluated lime use in literature in addition to building/application methods throughout the US, (lime) stabilized soils perform superior to non-stabilized soils provided materials, architecture, and construction are appropriately taken into account (Team, 2024). Among other advantages, reducing the number of layers in the pavement's structural design that comes after stabilized soil reduces the requirement for virgin material and saves a significant amount of money. The capacity of treated soil to shrink or swell in addition to the detrimental effects of freeze-thaw cycles is reduced when stabilized soils form a solid monolith which reduces permeability.

Soil stabilization may be used to enhance in-situ, or natural state, soils without requiring expensive remove-and-replace processes. Creating roads, parking lots, building sites, runways, and other constructions often results in weakening the naturally wet soils. They may be treated with chemicals to improve engineering properties such as moisture content and flexibility and to boost strength during soil stabilization and modifications. Although they may be used for environmental projects instead of regular construction activities, ex-situ, or off-site, soil stabilizing techniques are not always feasible. Soil parameters are examined during pre-project testing, which may assist in identifying the soil's reactivity. Testing is necessary for soil stabilization to ensure that the appropriate product is used for every undertaking and that there is sufficient stabilizing agent available for stabilizing the soil permanently.

In reactive soils, lime treatment may provide permanent, long-lasting strength that leads to soil stability. A soil that has a plasticity index (PI) of 10 or higher and at least 25% of its particles passing through a 75-micron screen (clay) is typically an excellent candidate for lime stabilization, in accordance to the National Lime Association. It's crucial to avoid hastily ruling out choices without doing your homework, However, testing has shown significant improvements in soils that didn't satisfy that condition. Almost invariably, fine-grained soils with moderate to high flexibility are "prime for lime.” The characteristics of lime-stabilized soil concrete are seen in Table 12.

Table 12: Illustrates the characteristics of lime-stabilized soil concrete.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	19.1	MPa (Mega-Pascals)
2	Flexural Strength	0.8	MPa
3	Tensile Strength	2.37	MPa
4	Water permeability	2.42×10^{-6}	(m/s)
5	Elastic Modulus	22,000	MPa
6	Thermal Conductivity	0.2	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

The hydraulic (LCC), demonstrates superior durability and water resistance compared to other LCCs. The table highlights key characteristics of this material, emphasizing its high performance in various structural and environmental conditions. The compressive strength is noted at 45.5 MPa, which indicates the material’s ability to withstand substantial loads, making it suitable for applications requiring high durability in Table 13. When it comes to resisting bending and stretching forces, the material has a flexural strength of 3 MPa and a tensile strength of 4.11 MPa. The water permeability is 4.40×10^{-6} m/s reflecting great resistance properties towards water. The durability of the material when exposed to water is increased by this low permeability. In addition, the value of elastic modulus is 28,992 MPa showing that it has a high capacity for returning to its initial form after being deformation. A value of 0.3 W/m·K for thermal conductivity indicates that good insulation is a property, while a Poisson ratio from 0.1 to 0.2 allows understanding of the material's deformation characteristics under stress. This combination of characteristics highlights the strength of hydraulic LCC and proves its suitability for use in projects that demand strong and water-resistant components.

Table 13: Represent the hydraulic LCC's high durability and water resistance properties as compared to other LLCs.

Sr. No.	Characteristic	Measured Value	Unit
1	Compressive Strength	45.5 MPa	MPa (Mega-Pascals)
2	Flexural Strength	3	MPa
3	Tensile Strength	4.11	MPa
4	Water Permeability (k)	4.40×10^{-6}	(m/s)
5	Elastic Modulus	28,992	MPa
6	Thermal Conductivity	0.3	W/m·K (Watts per meter-Kelvin)
7	Poisson Ratio	0.1-0.2	Unitless

The study findings indicate that hydraulic LCC is the best choice for most construction applications. This kind mixes hydraulic lime with cement and aggregates making it ideal for places where moisture resistance is very important. Hydraulic lime will set fast and gain strength even when in contact with water thus suitable for foundations, underwater structures, damp areas, etc. It is this durability together with its water resistance that makes it dependable for various constructions such as bridges, retaining walls, and basement walls. The inclusion of some cement will lead to higher strength as well as quicker curing than in cases of pure lime-based mixtures which are important for structural applications requiring high load-bearing capacities. Additionally, hydraulic lime cement concrete serves as a balance between the flexibility plus breathability of lime on one hand and concrete's tough character on the other hand helping avoidance from things like cracking and water ingress which occurs often in pure cement mixes thus making historical restorations possible besides modern constructions that require both conventional style and contemporary function.

5. Conclusion

This comprehensive study on the structural characteristics of lime-cement concrete has highlighted its unique blend of traditional and modern construction benefits. The investigation shows that within construction applications where flexibility and resilience are needed, lime-cement concrete is an efficient material due to the best combination of compressive strength, workability, and durability. In enhancing the plasticity and workability of the concrete, lime is used while its strength and durability come from cement leading to a composite material with varying structural requirements. Also, LCC shows that it can be environmentally friendly especially when because making lime requires less energy than other materials thus reducing carbon footprint levels. The outcome demonstrates the properties of the Hydraulic LCC, emphasizing its modulus of elasticity (28,992 MPa), thermal conductivity (0.3 W/m·K), tensile strength (4.11 MPa), compressive strength (45.5 MPa), flexural strength (3 MPa), and Poisson ratio (0.1-0.2). In addition, this substance can heal itself through carbonation, which makes it durable over time by reducing the need for frequent repairs. However, despite these advantages in themselves, more research should be done on how to optimize the ratio between lime and cement to maximize its structural performance under different environmental conditions.

Conflict of Interest

No conflict of interest was declared by the authors.

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