Utilizing Lightweight Expanded Clay Aggregate as Coarse Aggregate in Concrete

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Abstract. In recent years, the need for sustainable building materials has encouraged the use of lightweight concrete (LWC), as it offers advantages such as reduced dead load, improved workability and enhanced environmental efficiency. In this work, the mechanical and structural performance of lightweight concrete (LWC) is examined by partially replacing coarse aggregate with Lightweight Expanded Clay Aggregate (LECA). The insulation and energy efficiency benefits of LECA are also discussed, as these properties result from the expansion of natural clay at elevated temperatures. An extensive experimental investigation was performed to study the compressive, tensile and flexural strength properties of LECA-based concrete with replacement levels of 0%, 5%, 10% and 15%. M25 grade concrete was used, maintaining a fixed water–cement ratio of 0.43 and the mix included PPC, fine aggregate, coarse aggregate and water. For better accuracy, the concrete specimens were cured for periods of 7, 14 and 28 days and workability was measured using the slump test. The findings indicate that replacing 5% of coarse aggregate with LECA improves the compressive strength, showing an rise of nearly 5.35% at 28 days. At 10% replacement, the compressive strength further rise by 12.14%, while at 15% replacement, it drop by approximately 9.97% compared to conventional concrete. On the other hand, tensile and flexural strengths rise up to 10% LECA replacement, with maximum rises of 14.29% and 10.26%, respectively, and then drop by 7.14% and 6.41% at 15% replacement. This shows that an optimum amount of LECA can enhance the properties of lightweight concrete without affecting its structural integrity.

1 Introduction

Lightweight concrete (LWC) is widely adopted in the construction field owing to its reduced self-weight and improved workability [1]. Its low density, favourable strength-to-mass ratio and durability make it a viable and reliable option for lightweight concrete construction [2]. LECA is manufactured by expanding natural clay at high temperatures and offers a sustainable solution by minimizing the use of natural resources and lowering the

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carbon emissions related to building materials [3]. This study experimentally evaluates the mechanical and structural performance of lightweight concrete incorporating LECA. In addition to lowering the density of concrete, LECA improves its insulation properties, which makes it suitable for energy-efficient construction and seismic-resistant structures [4]. However, the performance of LECA-based concrete depends on factors such as aggregate size, mix design and curing conditions [5]. This study systematically investigates how these factors influence the compressive, splitting tensile, and flexural strength characteristics of LWC [6]. In an effort to enhance LECA-based concrete performance, the incorporation of fly ash as a supplementary cementitious material is examined [7]. This study presents a detailed assessment of lightweight concrete incorporating LECA to promote sustainable and efficient construction materials. The findings are intended to provide valuable insights for engineers and researchers engaged in the application of LECA for modern and high-performance structural systems.

2 Literature Review

Atheer S. et al. [8] investigated LECA-incorporated concrete and evaluated its mechanical properties. Most of the stress acting on a concrete structure comes from its own weight. A lightweight aggregate used in structural applications; it is a man-made product manufactured from heating natural clay in a horizontal kiln. Silica fume, Portland cement, light expanded clay aggregate as a complete substitute for coarse aggregate, fine aggregate and super plasticizer are a few of the materials used in this research. In this study, 10 mm-sized LECA is utilized as the lightweight aggregate in all LWC combinations. Anis A.M. et al. [9] This study experimentally examined structural response of deep beams cast with structural lightweight concrete incorporating LECA. The study focused on evaluating the ultimate strength and overall behaviour of deep section beams produced using lightweight concrete. A total of twelve deep structural beams were tested under two-point static loading. Structural lightweight concrete has broad applications, including bridges, offshore structures, multi-storey building systems, floor elements and prestressed or precast components. Prior to the main experimental phase, several trial mix proportions were designed, cast and tested to identify mixtures that satisfy the requirements of structural lightweight concrete standards. The selected mix was then adopted for specimen preparation and testing.

Othman M.L.B. et al. [10] conducted an experimental study on concrete incorporating expanded perlite aggregate (EPA) and expanded clay aggregate (LECA). It is not desirable to use precast concrete units with large self-weight components to construct because they always need more heavy machinery, which complicates transportation and necessitates stronger supporting components, both of which have the tendency to render overall construction costs higher. LECA products are typically available in size ranges of 4–6 mm, 6–10 mm and 10–16 mm. It was anticipated that the use of LECA and EPA combined to substitute part of the natural aggregates will generate lightweight concrete that might be stronger than the one achieved by using EPA alone and possibly lighter than the one achieved by using LECA alone. 10 mm crushed aggregate was the largest size of coarse material available. In the meantime, sieve analysis indicated that 27.6% of the fine aggregate particles were smaller than 600 μm. LECA along with EPA was used to substitute part of the coarse and fine aggregates. To reduce the excessive water percentage and achieve the same effective water/cement ratio for all mixtures, the LWAs were submerged in water to cope with the excessive water absorptions of LECA and EPA.

Shaalan et al. [11] investigated the mechanical performance of steel fiber–reinforced lightweight aggregate concrete (LECA). Steel fibers combined with expanded clay aggregate were incorporated to evaluate the structural behavior of lightweight coarse aggregate concrete (LWAC). Concrete specimens used in this research were all cast and cured using normal tap water. All conventional steel moulds were cleaned, coated with a release agent, and oiled internally 24 hours prior to casting.

Manish Yadav et al. [12] investigated the repair of lightweight concrete utilizing LECA led to lightweight concrete using LECA aggregates and came to such a conclusion. The primary objective of this research was to achieve weight reduction in structural elements. Lightweight expanded clay aggregate (LECA) possesses a porous structure, resulting in higher water absorption than standard aggregates. The water–cement ratio plays a critical role in determining the behaviour of concrete. Variations in this parameter influence both mechanical and durability properties. For this study, mixes were prepared using water–cement ratios of 0.35, 0.40, and 0.42. With a good density and as the density rises, the mixture is more workable. Chaitanya et al. [13] evaluated the role of LECA in enhancing the strength development of self-curing concrete.

A review of prior investigations was conducted to assess the potential of expanded clay LWA for use in structural concrete. The enlarged clay manufacturing process has been thoroughly examined, as have other production parameters that significantly affect aggregate quality. An analysis of the physical and strength-related properties of expanded clay LWCA was carried out. The review yielded the following conclusions. Expanded clay aggregate was used to create lightweight, self-compaction concrete. Numerous experimental studies have been documented in a number of instances. Shi [14] had reported six examples of self-compacting lightweight concrete application in Japan, pertaining to bridge decks, structural panel strengthening, and repair work. Additionally, a few laboratory searches have been conducted, mostly in the past five years. These experiments typically include roughly 0.3 m^3/m^3 light weight particles.

3 Material Study

This investigation evaluates the Strength and performance of lightweight concrete produced using LECA. The mix was prepared using Portland Pozzolana Cement, fine aggregate, Natural coarse aggregate was replaced with LECA in partial and full proportions, maintaining a consistent water–cement ratio of 0.43. Standard specimens were cast in conventional moulds to understand how the concrete performs when subjected to compression, tension and bending. To minimize rapid water absorption during mixing, the Before batching, LECA was saturated by immersion in water. The flow behaviour of the concrete mix was subsequently assessed by means of a slump test. The specimens were removed from the moulds 24 hours after casting and subsequently cured in water for 7, 14, and 28 days before undergoing strength evaluation.

3.1 Cement

The main binding material used in this investigation was Portland Pozzolana Cement (PPC) in accordance with IS 1489 (Part 1): 2015 [15]. PPC was selected due to its consistent strength development, durability characteristics and compatibility with lightweight aggregates such as LECA. Its major oxides promote proper hydration and improve adhesion within the cement matrix and surrounding aggregates. The relatively fine particle size of PPC enhances the cohesiveness and workability of the concrete mixture. The interaction of cement with water leads to the formation of C–S–H gel, the main phase governing the mechanical properties of concrete. To prevent premature moisture absorption and maintain material quality, the cement was stored under dry, moisture-controlled conditions prior to use.

Table 1. Physical Characteristics of Cement

Parameter	**Observed Value**
Specific gravity of cement	3.0
Fineness	3.8%
Soundness	1.1 mm
consistency	29%
Initial Setting Time	86 min
Final Setting Time	390 min

3.2 Fine Aggregate

Sand is a very necessary building element, but it must be carefully and carefully chosen whenever possible. Sand used in building needs to be pure and devoid of contaminants and waste stones. The fineness of the available sands should be assessed, and based on that assessment, their utilization for the various construction purposes should be planned.

Table 2. Physical Properties of Fine Aggregate

Parameter	**Observed Value**
Specific gravity	2.62
Water Absorption	2%
Fineness Modulus	3.12

3.3 Coarse Aggregate

Concrete is made with coarse aggregate. They could take the shape of naturally existing gravel or irregularly fragmented stone. Coarse aggregates are materials that are too big to through a 4.75 mm screen.

Table 3. Physical Properties of Coarse Aggregate

Parameter	**Observed Value**
Specific gravity	2.79
Fineness Modulus	6.43
Flakiness Index	6.84%
Elongation Index	10.04%
Abrasion	14.78%
Impact value	5.54%

3.4 Water

For mixing and curing, potable water was utilised.

3.5 LECA

Lightweight expanded clay aggregate (LECA), sometimes referred to as expanded or bloated clay, is a manufactured lightweight aggregate obtained by heating clay in a rotating kiln at elevated temperatures of approximately 1200 °C. At such elevated temperatures, the material undergoes expansion, producing hard, porous and lightweight granules. LECA is available in various particle size distributions, generally ranging from 0.1 mm to 20 mm, with commonly supplied grades such as 0–2 mm, 2–4 mm, 4–10 mm and blended fractions of 0–20 mm. The corresponding bulk densities are approximately 510, 330, 250 and 280 kg/m³, respectively. Owing to its cellular internal structure, LECA exhibits advantages including low unit weight, enhanced thermal insulation capacity, sound attenuation properties and resistance to moisture penetration, which make it well suited for diverse structural and non-structural construction applications.

Table 4. Physical Properties of LECA

Parameter	**Observed Value**
Specific gravity	0.56
Water absorption	19.04

Fig. 1. LECA

3.6 Mix Design

The recommended mix proportions are specifically designed for the M25 grade of concrete. The table below displays the calculated proportions for the mix.

Table 5. Mix Ratio

Grade of Concrete	**Water Cement Ratio**	**Mix Ratio**
M25	0.43	1:1.46:2.57

4 Result and Conclusion

The experimental investigation demonstrates that including LECA considerably influences the mechanical performance of M25 grade composition. An improvement in strength characteristics was observed at lower replacement levels, whereas a gradual reduction occurred with higher percentages of LECA incorporation. This behaviour mainly occurs because LECA provides internal curing, which improves the bonding between the aggregate particles and the surrounding cement paste.

4.1 Compressive Strength

Compressive strength increased at 5% LECA, showing an increase of 5.35% at 28 days compared to the conventional mix. As the percentage of replacement rise to 10%, the compressive strength further rise achieving a maximum rise of 12.14%. This rise in strength can be attributed to enhanced internal curing and hydration along with better interaction between the particles within the concrete matrix. However, at 15% LECA replacement, the compressive strength drops by approximately 9.97% relative to the control mix. The decline in compressive strength at higher replacement levels can be attributed to the relatively reduced density and enhanced porosity of LECA, which rises the porosity of the concrete mix, decreasing its load-bearing capacity.

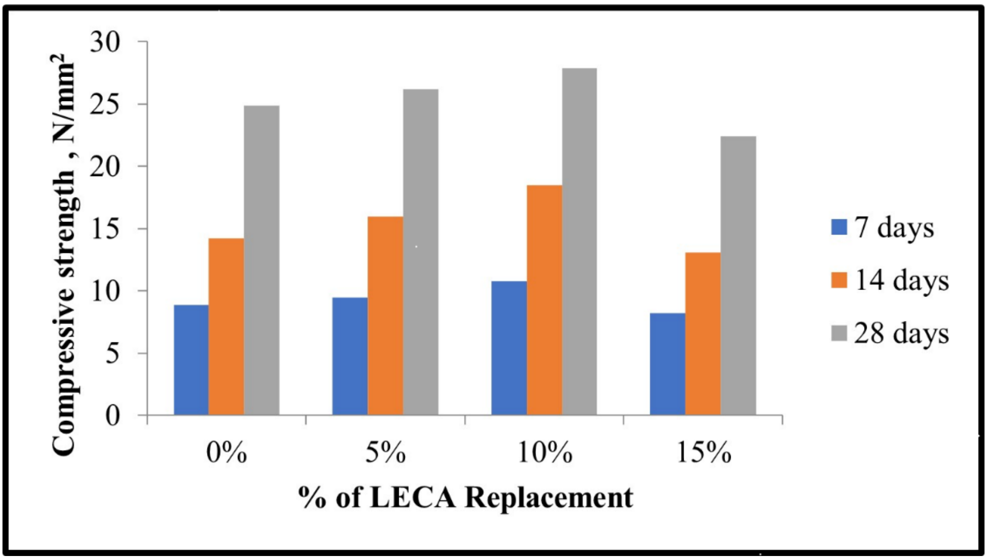

Fig. 2. Compressive Strength Results

4.2 Tensile Strength

The splitting tensile capacity showed a comparable pattern, improving upon adding LECA replacement up to 10%. It rise by 5.36% at 5% LECA replacement, and by 14.29% at 10% LECA replacement, the latter showing the highest improvement. This shows improved bonding and better stress distribution in the concrete matrix with moderate LECA content. The drop in tensile strength at higher LECA replacement values of 7.14% at 15% LECA replacement compared to conventional concrete was due to the rise void content and the decreasing stiffness of the lightweight aggregate.

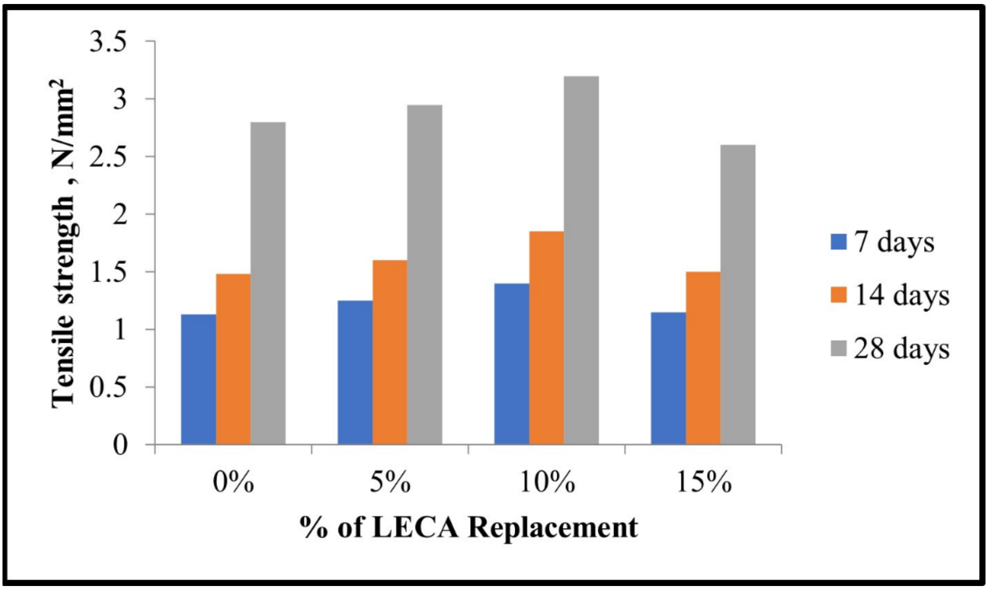

Fig. 3. Tensile Strength Results

4.3 Flexural Strength

Flexural performance results also improved until 10% LECA replacement. At 5%, the bending strength rise by 5.13% and 10%, the maximum increment of 10.26% was achieved. The better hydration and ITZ characteristics led to an enhanced flexural resistance to crack propagation and bending stresses. At 15% LECA replacement, the bending strength of the mix drop by 6.41% as compared to the control mix. The results can be attributed to the higher porosity from the excess LECA content, which adversely affected the bending resistance of the concrete.

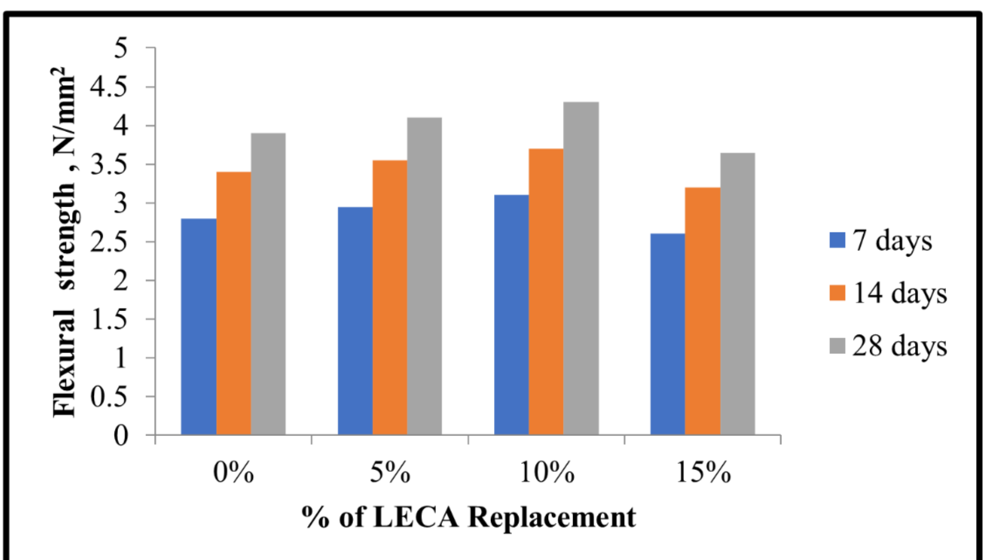

Fig. 4. Flexural Strength Results

5 Conclusion

The present investigation evaluates the effect of partially substituting coarse aggregate with LECA on the strength performance of M25 grade mix. The results indicate that compressive, split tensile and flexural strengths improved up to a 10% replacement level, with maximum enhancements of 12.14%, 14.29% and 10.26% compared to the control mix. Concrete strength declined at 15% LECA replacement, attributed to the increased porosity and lightweight nature of the aggregate. Based on the experimental findings, incorporating LECA up to 10% as a partial coarse aggregate replacement material can be considered optimal for enhancing the strength properties of lightweight concrete.

Abbreviations

LECA	Lightweight Expanded Clay Aggregate
LWC	Lightweight Concrete
PPC	Portland Pozzolana Cement
IS	Indian Standards
MPA (MPa)	Megapascal
C-S-H	Calcium Silicate Hydrate
EPA	Expanded Perlite Aggregate
LWCA	Lightweight Coarse Aggregate

Author Contributions

Dr. Subashree Paramasivan formulated the study, supervised the practical investigation and was responsible for reviewing and finalizing the manuscript. **Santhoshkumar Bojarajan, Shenbagamoorthi Arumugam, Abdul Raheem Jalaludheen, and Murali Prasath Mahendran** were actively involved in conducting the laboratory experiments, collecting and analysing the data, and preparing the preliminary version of the manuscript. All authors have examined and endorsed the final manuscript.

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