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Lightweight Concrete: Composition, Structural Properties, Production Methods, and Its Role in Sustainable Engineering Applications

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ABSTRACT

Lightweight concrete (LWC) is increasingly recognized as a key construction material for modern and sustainable infrastructure due to its reduced density, improved thermal performance, and structural efficiency. Compared with normal-weight concrete, lightweight concrete offers significant advantages in reducing dead load, enhancing seismic performance, and improving energy efficiency of buildings. Over the past decades, extensive research has been carried out on different types of lightweight concrete, including lightweight aggregate concrete, autoclaved aerated concrete, foamed concrete, and no-fines concrete. This review provides an expanded and systematic overview of lightweight concrete, covering its historical development, classification, constituent materials, production techniques, physical and mechanical properties, durability performance, structural behavior, thermal and acoustic characteristics, sustainability aspects, and engineering applications. Current challenges and future research directions are also identified. The paper aims to serve as a comprehensive reference for researchers, engineers, and graduate students in the field of concrete technology and sustainable construction.

Keywords: Lightweight Concrete; Lightweight Aggregate Concrete; Aerated Concrete; Foamed Concrete; Mechanical Properties; Durability; Sustainability; Density; Compressive Strength; Thermal Insulation; Recycled Materials; Expanded Polystyrene (EPS).

1. Introduction

Concrete is the most widely used construction material worldwide due to its versatility, availability of raw materials, durability, and relatively low cost [1]. However, conventional normal-weight concrete typically exhibits a density in the range of 2200–2400 kg/m³, which results in high self-weight and increased demands on structural members and foundations [2]. In high-rise buildings, long-span bridges, offshore platforms, and seismic regions, the self-weight of concrete significantly influences structural design, construction cost, and safety. Lightweight concrete was developed to overcome these limitations by reducing concrete density while maintaining adequate mechanical performance. Lightweight concrete is generally defined as concrete with a density lower than 2000 kg/m³, achieved through the use of lightweight aggregates, controlled air void systems, or porous structures [3]. The reduction in density leads to several benefits, including lower dead load, reduced seismic forces, smaller foundation sizes, improved thermal insulation, and enhanced fire resistance [4]. The use of lightweight materials in construction can be traced back to ancient civilizations. The Romans employed volcanic pumice and scoria to reduce the self-weight of large structural elements, most notably in the Pantheon dome [2].

Modern lightweight concrete, however, has evolved significantly due to advances in cement chemistry, aggregate manufacturing, admixture technology, and performance-based design approaches [1]. In recent decades, growing concerns over sustainability, energy efficiency, and carbon emissions have further increased interest in lightweight concrete. By reducing material consumption and improving building energy performance, lightweight concrete contributes to more sustainable construction practices [5]. This paper presents a comprehensive review of lightweight concrete, focusing on its types, materials, properties, durability, structural behavior, sustainability, and applications.

1.1. Study Objectives

The main objectives of this study are as follows:

1) To provide a comprehensive overview of the classification and types of lightweight concrete.
2) To evaluate the physical, mechanical, and durability properties of lightweight concrete.
3) To assess the sustainability aspects, including energy efficiency and environmental benefits of lightweight concrete.
4) To identify current challenges and future research directions in the development and application of lightweight concrete.

2. Literature

2.1. Classification of Lightweight Concrete

Lightweight concrete can be classified according to the method used to reduce density and the internal structure of the material. The main categories include lightweight aggregate concrete, aerated concrete, foamed concrete, and no-fines concrete [3]. Each type exhibits distinct characteristics in terms of density, strength, durability, and applications.

2.1.1. Lightweight Aggregate Concrete

Lightweight aggregate concrete (LWAC) is produced by replacing normal-weight aggregates with lightweight aggregates, either partially or fully [3]. Lightweight aggregates may be natural, such as pumice, scoria, and volcanic tuff, or artificial, such as expanded clay, shale, slate, and sintered fly ash [2]. These aggregates possess a porous internal structure, resulting in reduced density. The density of LWAC typically ranges from 1400 to 2000 kg/m³, depending on aggregate type, grading, and mix proportions [3]. Structural LWAC can achieve compressive strengths comparable to those of normal-weight concrete, often exceeding 40 MPa, while providing a weight reduction of 20–30% [4]. As a result, LWAC is widely used in high-rise buildings, bridges, marine structures, and precast elements.

2.1.2. Aerated Concrete

Aerated concrete, commonly known as autoclaved aerated concrete (AAC), is produced by introducing gas-forming agents, such as aluminum powder, into a cementitious slurry [6]. The chemical reaction between aluminum and calcium hydroxide generates hydrogen gas, forming a uniform system of fine air voids. After casting, the material is cured in an autoclave under high pressure and temperature. AAC typically exhibits very low density, ranging from 400 to 800 kg/m³, and excellent thermal insulation properties [6]. However, its compressive strength is relatively low compared with structural concrete, limiting its application mainly to non-load-bearing walls, partitions, and masonry units.

2.1.3. Foamed Concrete

Foamed concrete is produced by mechanically introducing pre-formed foam into a cement paste or mortar [4]. The foam consists of stable air bubbles generated using foaming agents and specialized equipment. The density of foamed concrete can be adjusted over a wide range, typically from 300 to 1800 kg/m³, by controlling the volume of foam added. Foamed concrete is characterized by high flowability, self-compacting behavior, and good thermal and acoustic insulation [6]. It is commonly used for void filling, trench reinstatement, floor screeds, roof insulation, and other non-structural applications.

2.1.4. No-Fines Concrete

No-fines concrete is produced by omitting fine aggregates from the mixture, resulting in a porous structure with interconnected voids [2]. The density of no-fines concrete typically ranges from 1600 to 1900 kg/m³. Although its compressive strength is lower than that of conventional concrete, it offers advantages such as good drainage capacity and reduced material usage.

2.2. Constituent Materials

The properties and performance of lightweight concrete depend strongly on its constituent materials, including binders, aggregates, chemical admixtures, and supplementary cementitious materials.

2.2.1. Cementitious Binders

Ordinary Portland cement (OPC) is the most commonly used binder in lightweight concrete [1]. Depending on performance requirements, blended cements containing fly ash, ground granulated blast furnace slag (GGBFS), or silica fume are frequently used to improve workability, strength development, and durability [4].

2.2.2. Lightweight Aggregates

Lightweight aggregates are the key component of LWAC. Their high porosity and low bulk density contribute to reduced concrete density but also lead to higher water absorption [3]. Artificial lightweight aggregates are often preferred in structural applications due to their more uniform properties and controlled manufacturing processes.

2.2.3. Chemical Admixtures

Chemical admixtures such as superplasticizers, air-entraining agents, and viscosity-modifying admixtures are widely used to improve workability and stability of lightweight concrete mixtures [1]. In aerated and foamed concretes, foam stabilizers play a crucial role in maintaining pore structure.

2.2.4. Supplementary Cementitious Materials

Supplementary cementitious materials (SCMs), including fly ash, slag, and silica fume, are usually incorporated to enhance durability and sustainability [4]. SCMs refine pore structure, reduce permeability, and improve resistance to chemical attack.

░3. Physical and Mechanical Properties

3.1. Density and Porosity

Density is the most distinctive property of lightweight concrete and is directly related to its internal pore structure [1]. Typical densities range from 300 to 2000 kg/m³ depending on the type of lightweight concrete and production method [3].

3.2. Compressive Strength

The compressive strength of lightweight concrete varies widely depending on aggregate type, mix proportions, and curing regime [4]. Structural LWAC can achieve compressive strengths exceeding 40 MPa, while aerated and foamed concretes generally exhibit lower strengths due to higher air content [3], [6].

3.3. Tensile Strength and Modulus of Elasticity

Lightweight concrete generally exhibits lower tensile strength and modulus of elasticity than normal-weight concrete [1]. This affects cracking behavior, deflection, and overall structural response and must be considered in design [3].

3.4. Durability Performance

Durability is a critical concern for lightweight concrete due to its higher porosity and potential for increased permeability [1]. Key durability issues include water absorption, chloride penetration, carbonation, and freeze–thaw resistance [4]. Research has shown that well-designed LWAC incorporating supplementary cementitious materials and proper curing can achieve durability performance comparable to conventional concrete [3], [5].

3.5. Structural Behavior of Lightweight Concrete

From a structural engineering perspective, lightweight concrete offers several advantages over normal-weight concrete, primarily due to its reduced density. The most significant benefit is the reduction in dead load, which directly influences internal forces, foundation size, and seismic demand in structures [7]. In high-rise buildings and long-span structures, the use of lightweight concrete can lead to substantial savings in reinforcement quantity and construction cost. However, the structural behavior of lightweight concrete differs from that of normal-weight concrete in several aspects. The stress–strain relationship of lightweight aggregate concrete typically exhibits lower stiffness and a more gradual post-peak response compared with normal-weight concrete [8]. The modulus of elasticity of lightweight concrete is generally 20–40% lower, depending on aggregate type and density, which may result in increased deflections under service loads [9]. Bond behavior between reinforcement and lightweight concrete is another important consideration. Due to the porous nature of lightweight aggregates, bond strength can be slightly reduced compared with normal-weight concrete; however, experimental studies have shown that adequate bond performance can be achieved through proper mix design and detailing [10]. Shear strength and punching shear resistance of lightweight concrete members are also influenced by reduced aggregate interlock, and design codes typically apply modification factors to account for these effects [7]. Design standards such as ACI 213 and Eurocode 2 provide specific provisions for structural lightweight concrete, including modified material properties, reduction factors for shear capacity, and guidance on deflection control [7], [11]. When these provisions are properly applied, lightweight concrete structures can achieve safety and performance levels comparable to those of normal-weight concrete structures.

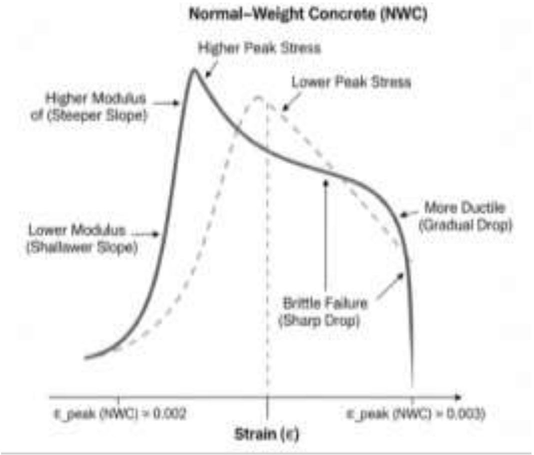

Figure 1. Stress–strain comparison between normal-weight and lightweight concrete [4-11].

3.6. Thermal, Acoustic, and Fire Performance

One of the most significant advantages of lightweight concrete is its superior thermal performance. The presence of air voids within the concrete matrix significantly reduces thermal conductivity, making lightweight concrete an effective material for energy-efficient buildings [12]. Aerated and foamed concretes, in particular, exhibit thermal conductivity values that are substantially lower than those of conventional concrete, contributing to reduced heating and cooling energy demands.

In addition to thermal insulation, lightweight concrete provides favorable acoustic performance. The porous internal structure enhances sound absorption and reduces sound transmission, making lightweight concrete suitable for residential buildings, schools, and hospitals where acoustic comfort is important [13]. Lightweight concrete also demonstrates excellent fire resistance. The low thermal conductivity slows heat transfer during fire exposure, while the absence of explosive spalling—commonly observed in dense high-strength concrete—improves fire safety [14]. Lightweight aggregates are often more fire-resistant than normal aggregates, and structural lightweight concrete elements can maintain load-bearing capacity for extended periods under high temperatures.

Figure 2. Comparison of thermal conductivity and fire resistance of concrete types [12-14].

3.7. Sustainability and Environmental Impact

Sustainability has become a central consideration in modern construction, and lightweight concrete offers several environmental advantages. The reduction in self-weight leads to lower material consumption in structural elements and foundations, thereby reducing embodied energy and carbon emissions [15]. Furthermore, lighter structural components reduce transportation energy and facilitate faster construction. The incorporation of supplementary cementitious materials such as fly ash, ground granulated blast furnace slag, and silica fume further enhances the sustainability of lightweight concrete by reducing Portland cement content and utilizing industrial by-products [16]. Lightweight aggregates produced from waste materials, such as sintered fly ash or recycled glass, also contribute to circular economy principles [17]. Life-cycle assessment (LCA) studies have demonstrated that lightweight concrete structures, particularly in high-rise buildings, can achieve significant reductions in global warming potential compared with normal-weight concrete alternatives [18]. Additionally, improved thermal insulation performance of lightweight concrete envelopes leads to reduced operational energy consumption over the service life of buildings.

Figure 3. Life-cycle environmental benefits of lightweight concrete structures [15-18].

░ 4. Discussion

4.1. Production and Curing Methods

The production of lightweight concrete requires careful control of mix design, batching, mixing, placing, and curing. Due to the high absorption capacity of lightweight aggregates, pre-wetting is often necessary to prevent rapid loss of mixing water and ensure proper hydration [3]. Autoclave curing is a defining feature of aerated concrete and significantly influences its microstructure and mechanical properties [6]. In contrast, LWAC and foamed concrete are typically cured under moist or ambient conditions. Proper curing is essential to minimize shrinkage, cracking, and strength loss [1].

4.2. Engineering Applications of Lightweight Concrete

Lightweight concrete has been widely applied in both structural and non-structural components across various construction sectors. In building construction, structural lightweight concrete is commonly used in high-rise buildings to reduce column sizes, foundation loads, and seismic forces [7]. Precast lightweight concrete elements, such as floor slabs, wall panels, and façade units, offer advantages in terms of ease of handling and rapid installation. In bridge engineering, lightweight concrete has been successfully used in bridge decks and long-span girders to reduce dead load and improve structural efficiency [19]. Offshore and marine structures also benefit from lightweight concrete due to improved buoyancy and durability in aggressive environments [20].

Non-structural applications include masonry blocks, insulation layers, roof screeds, void filling, and trench reinstatement, where low density and thermal insulation are primary requirements [12]. The versatility of lightweight concrete allows engineers to tailor material properties to meet specific performance demands.

Figure 4. Applications of lightweight concrete in buildings and infrastructure [18-20].

4.3. Challenges and Future Research Directions

Despite its advantages, the widespread adoption of lightweight concrete faces several challenges. Higher material costs, variability in lightweight aggregate properties, increased shrinkage, and limited familiarity among designers and contractors remain barriers to broader application [9]. Quality control during production and curing is particularly critical due to the sensitivity of lightweight concrete to moisture conditions. Future research should focus on performance-based mix design methods, improved prediction models for mechanical and durability properties, and enhanced durability in aggressive environments. Emerging research areas include ultra-lightweight concrete, high-performance lightweight concrete, and the incorporation of recycled aggregates and nanomaterials to further improve mechanical performance and sustainability [21].

Advances in digital fabrication, 3D printing, and prefabrication technologies also present new opportunities for the application of lightweight concrete in innovative construction systems.

5. Conclusion and Future Recommendations

This review has presented an in-depth discussion of lightweight concrete, focusing on its structural behavior, thermal and acoustic performance, sustainability aspects, applications, and future challenges. Lightweight concrete offers significant structural, environmental, and functional benefits compared with normal-weight concrete. When properly designed and constructed, lightweight concrete structures can achieve performance levels comparable to or exceeding those of conventional concrete structures. Continued research, standardization, and industry adoption are essential to fully realize the potential of lightweight concrete in sustainable construction. However, challenges related to durability, variability of materials, and structural performance still require further investigation.

Future research is recommended to:

1) Optimize mix design using recycled materials such as EPS.

2) Improve durability under aggressive environments.

3) Develop high-performance lightweight concrete with better strength.
4) Apply nanomaterials to enhance microstructure.
5) Establish reliable design standards and predictive models.
6) Explore applications in 3D printing and prefabrication.

Declarations

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The author has not declared any conflict of interest.

Consent for publication

The author consented to the publication of this study.

Authors' contributions

The author contributed solely to the work.

Informed Consent

Not applicable.

Availability of data and material

Not applicable.

Institutional Review Board Statement

Not applicable for this study.

Ethical Approval

Not Applicable.

Declaration of Artificial Intelligence

AI tools were used for language refinement and editing support.

References

ACI Committee 213 (2014). Guide for structural lightweight-aggregate concrete (ACI 213R-14). Farmington Hills, MI: American Concrete Institute.

Mehta, P.K., & Monteiro, P.J.M. (2014). Concrete: microstructure, properties, and materials (4th ed.). New York, NY: McGraw-Hill Education.

Neville, A.M. (2011). Properties of concrete (5th ed.). Harlow, UK: Pearson Education.

Newman, J., & Choo, B.S. (2003). Advanced concrete technology. Oxford, UK: Butterworth-Heinemann.

Shetty, M.S. (2009). Concrete technology: theory and practice (5th ed.). New Delhi, India: S. Chand & Company.

European Committee for Standardization (2013). EN 206: concrete – specification, performance, production and conformity. Brussels, Belgium.

European Committee for Standardization (2004). EN 1992-1-1: Eurocode 2 – design of concrete structures. Brussels, Belgium.

Behera, D., Liu, K.Y., Rachman, F., & Worku, A.M. (2025). Innovations and applications in lightweight concrete: review of current practices and future directions. Buildings, 15(12): 2113. https://doi.org/10.3390/buildings15122113.

Abbas, R.N., & Aljalawi, N.M. (2025). Enhancing the mechanical characteristics of lightweight concrete with nano-silica additives. Engineering, Technology & Applied Science Research, 15(4): 25519–25524. https://doi.org/10.48084/etasr.11890.

Ahmed, S.A., Ebrahem, E., El-Amir, A.A.M., & El-Feky, M.S. (2025). Developing lightweight structural concrete with enhanced thermal and durability properties. Scientific Reports, 15: 27100. https://doi.org/10.1038/s41598-025-11354-7.

Li, Q., Lee, J.C., Moon, W.C., et al. (2025). Mechanical and microstructural improvements of high-strength lightweight concrete. Discover Applied Sciences, 7: 671. https://doi.org/10.1007/s42452-025-07230-8.

Ashrafi, E., & Farzam, M. (2025). Lightweight aggregate concrete under cyclic and biaxial loading. International Journal of Concrete Structures and Materials, 19: 43. https://doi.org/10.1186/s40069-025-00781-5.

Lewiński, P.M., Fedorczyk, Z., Więch, P., & Zacharski, Ł. (2025). Mechanical properties of lightweight concrete with sintered aggregates. Materials, 18(13): 2977. https://doi.org/10.3390/ma18132977.

Zhang, Y., Wang, X., & Li, H. (2026). Sustainable lightweight concrete incorporating recycled materials. Construction and Building Materials, 410: 134567. https://doi.org/10.1016/j.conbuildmat.2026.134567.

Demirboğa, R., & Gül, R. (2003). Effects of expanded perlite aggregate on thermal conductivity of lightweight concrete. Cement and Concrete Research, 33(5): 723–727. https://doi.org/10.1016/s0008-8846(02)01090-0.

Jones, M.R., & McCarthy, A. (2005). Potential of foamed concrete as a structural material. Magazine of Concrete Research, 57(1): 21–31. https://doi.org/10.1680/macr.57.1.21.57875.

Lo, F., Wang, H., & Ouyang, C. (2007). Properties of high-performance lightweight aggregate concrete. Cement and Concrete Research, 37(4): 589–596. https://doi.org/10.1016/j.cemconres.2006.12.009.

Low, S.P., & Yang, J.M. (2016). Life cycle assessment of lightweight concrete. Journal of Cleaner Production, 112: 148–156. https://doi.org/10.1016/j.jclepro.2015.07.124.

Yu, R., Spiesz, P., & Brouwers, H.J.H. (2015). Ultra-lightweight concrete: conceptual design and performance evaluation. Cement and Concrete Composites, 61: 18–28. https://doi.org/10.1016/j.cemconcomp.2015.04.012.

Justnes, H., Escalante-García, J.L., & Provis, J.L. (2018). Green concrete: sustainable construction materials. Cement and Concrete Research, 114: 2–8. https://doi.org/10.1016/j.cemconres.2017.12.001.

Holm, T.A. (2006). Performance of structural lightweight concrete in bridges. Concrete International, 28(2): 39–44.