

## STUDY AND ANALYSIS OF RCC WALL USING LIGHT WEIGHT AGGREGATES IN APARTMENT BUILDING (G+3 FLOORS)

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**ABSTRACT** The study addresses a multifaceted array of challenges and concerns surrounding the design and evaluation of lightweight concrete walls. In the construction industry, the demand for such walls is on the rise, driven by the potential advantages they offer, including improved energy efficiency, reduced environmental impact, and enhanced mobility in various applications. However, several complex problems need resolution: The first issue revolves around the selection of appropriate lightweight composite materials. Choosing the most suitable materials for specific applications requires a delicate balance between mechanical properties, cost-effectiveness, and weight-saving potential. Another challenge lies in the quest to optimize the structural efficiency of lightweight concrete walls. Achieving structural efficiency that not only meets but surpasses performance requirements necessitates the development of innovative design methodologies while minimizing weight and material usage.

### INTRODUCTION

Lightweight concretes are not a recent advancement in concrete technology but have been known since ancient times, serving as the predecessors to today's concrete. The earliest European references to lightweight concrete date back to two thousand years ago during the early Roman Empire. One of the most famous examples is the Pantheon in Rome, Italy, constructed around 128 A.D., which impressively demonstrated the systematic use of various natural lightweight aggregates in opus caementitium [Lamprecht, 1996]. However, after the fall of the Roman Empire, the use of lightweight concrete declined due to the limited availability and variability of natural volcanic aggregates. The turning point in material technology came in the 19th and 20th centuries with the development and production of industrially produced lightweight aggregates [Chandra, 2002 and Expanded Clay and Slate Institute, 1991].

Initially, the use of expanded aggregates was restricted to the United States Navy, with the U.S. Emergency Fleet Building Corporation establishing a shipbuilding program during World War I. In 1918, the Atlantis became the first ship built under this program, and a total of fourteen lightweight concrete ship hulls were constructed. These early experiences led to the deployment of 104 supply ships during World War II, with cargo capacities ranging from 3,200 to 140,000 tons [Holm, 1980]. The successful use of lightweight concrete in shipbuilding paved the way for its introduction in structural engineering. The first commercial plant for producing expanded aggregates was established in 1920 in Kansas, USA, providing uniform quality and composition advantages over natural aggregates. In the 1920s, several bridges were constructed using expanded slate as aggregate in

lightweight concrete. Over fifty years later, more than 200 lightweight concrete bridges were built in the United States and Canada [Raithby, 1981]. In the mid-20th century, the use of lightweight concrete in structural engineering intensified, resulting in the construction of multi-story high-rise buildings such as the Prudential Plaza Building and the Marina City Towers in Chicago. However, the adoption of lightweight concrete in architecture remained limited to individual cases [Thinel, 2007].

The oil crisis in 1973 prompted Germany to reconsider its energy consumption policies, leading to the implementation of the Energy Saving Act [Bundesregierung, 1977]. This legislation made energy-efficient buildings a political obligation, and monolithic exterior walls made of lightweight concrete with economical thickness could no longer meet the increased thermal insulation requirements.

Since the 1990s, Germany has revised its technical regulations for concrete construction, leading to an upswing in the use of lightweight concretes. Ongoing technological and scientific developments have contributed to this trend, with a focus on reducing concrete density while maintaining strength. In recent years, monolithic structures made of fair-faced lightweight concretes in the lowest strength and density classes have gained popularity in Europe. These structures allow for the construction of finished walls in a single operation, eliminating the need for multi-layer wall structures. The choice of massive lightweight concrete walls is typically based on the desire for flexible and easily shaped architecture, along with the physical properties of lightweight concrete, including low density, favorable building physics, high fire resistance, and excellent durability [Cavalline et.al, 2017].

The latest stage in this development is known as infra-lightweight concrete (ILC) [Roberz, 2017]. Other researchers refer to similar material approaches using terms like Warmbeton, Architekturleichtbeton, or ultra-lightweight concrete [Yu et.al, 2015]. ILC aims to meet both structural requirements and thermal insulation standards, offering options for monolithic wall design that comply with current energy consumption regulations without requiring additional insulation materials. Nevertheless, building regulations still pose a challenge for the practical application of ILC. It is not yet a standardized building material, requiring project-specific or technical approvals, although it is commercially available. Lightweight concrete can be described as a type of concrete that incorporates an expanding agent, which increases the volume of the mixture while imparting additional qualities such as workability and reduced overall weight. It is notably lighter than conventional concrete and has found widespread use in various countries, including the USA, United Kingdom, and Sweden. The key features of lightweight concrete include its low density and thermal conductivity. Its advantages encompass a reduction in dead load, faster construction progress, and decreased costs associated with transportation and handling (ACI Committee, 2014). Lightweight concrete maintains its significant voids and avoids the formation of laitance layers or cement films when applied to a wall. The focus of this research pertains to the performance of aerated lightweight concrete. However, it's essential to maintain an appropriate water-cement ratio to ensure adequate cohesion between cement and water. Inadequate water content can lead to a lack of cohesion between particles, resulting in a reduction in concrete strength. Conversely, excessive water can cause cement to separate from the aggregate, forming laitance layers, which subsequently weakens the concrete's strength Lösch (2019).

**LIGHTWEIGHT CONCRETE**

There are various definitions of lightweight concrete, and this variability often leads to imprecision when discussing lightweight concrete. These differences pertain to factors such as strength, density, and the specific type of lightweight concrete being considered. For instance, the ACI 213R-14 "Guide for Structural Lightweight-Aggregate Concrete" outlines specific criteria, specifying a minimum cylinder strength of 17 MPa and an equilibrium density ranging from 1120 to 1920 kg/m<sup>3</sup> for structural lightweight concrete (SLC). For specified density concrete (SDC), there are no strength requirements, and the equilibrium density falls between 800 and 2240 kg/m<sup>3</sup>. High

strength lightweight concrete is classified as SLC when it achieves a compressive strength of 40 MPa at 28 days.

In Europe, structural lightweight concrete (LC) is addressed as a material in EN 206, and its application is regulated in EN 1992. The minimum strength class is LC8/9, referring to a characteristic cylinder strength of 8 MPa and a characteristic cube strength of 9 MPa. The design standard stipulates a minimum strength class of LC12/13. However, in Germany, due to limited practical experience, a technical approval is mandatory for strength classes LC70/77 and LC80/88. LC has an oven-dry density within the range of  $800 \geq \rho_d \leq 2000$  kg/m<sup>3</sup>. This density range is further divided into density classes, each with a span of 200 kg/m<sup>3</sup>. It's important to note that a flexible combination of strength and density classes is not always possible. Nevertheless, Figure 1 illustrates that specific LC strength classes necessitate particular density classes (D) for precise definition. In comparison to other types of lightweight concrete, LC has a dense cement matrix, and its surface closely resembles that of normal weight concrete (NC). The lightweight aggregates only become visible on a damaged or cut surface (Figure 2a), Thienel, 2020.

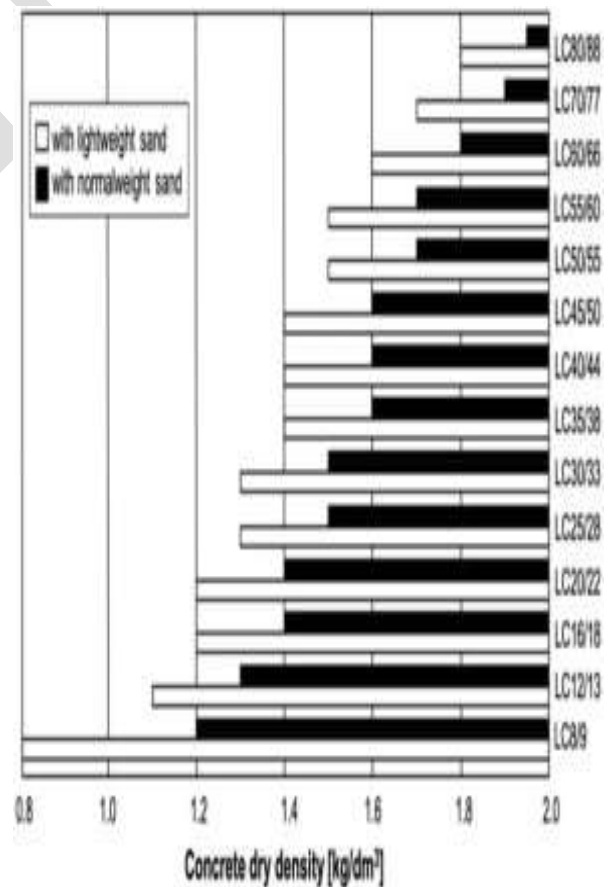


Figure 1.1: Correlation between strength classes and necessary dry density for LC (Thienel, 2019)

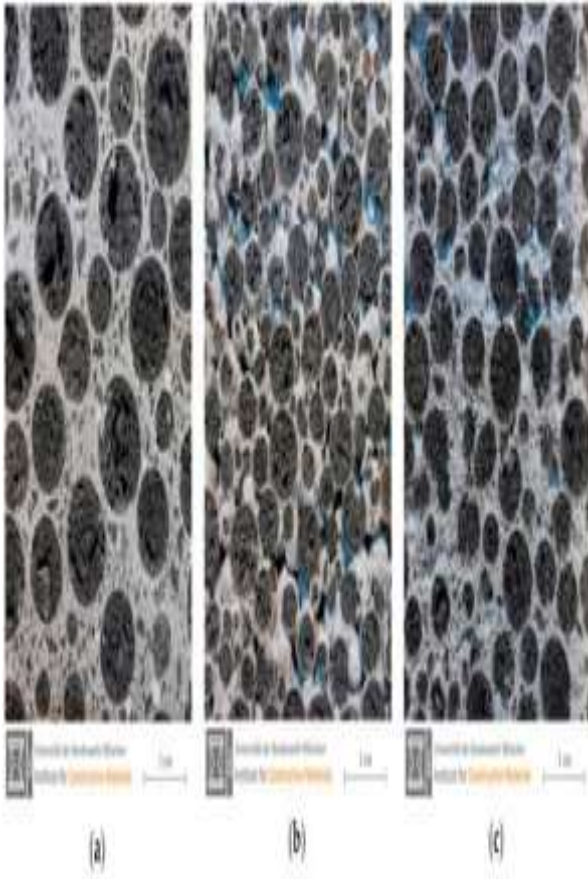


Figure 1.2: (a) Image of structural lightweight concrete (LC) with a dense matrix structure; (b) Image of the lightweight aggregate concrete (LAC) with open pore structure; (c) Image of LAC with a porous matrix filling the open pore structure. All three types of lightweight concrete are based on expanded clay from one producer as LWA.

Lightweight aggregate concrete with an open structure (LAC) differs significantly from the previously mentioned lightweight concrete (LC) and is defined by EN 1520. LAC's dry density falls within the range of  $400 \geq \rho_d \leq 2000 \text{ kg/m}^3$ . EN 1520 outlines strength classes for LAC, ranging from LAC 2 to LAC 25, based on the characteristic strength [MPa] of 100-mm cores drilled from LAC elements. LAC finds application in structural elements such as loadbearing walls, roof elements, slabs, beams, as well as non-structural components like noise barriers. The properties of LAC can be notably enhanced when its open structure is filled with a porous matrix, often in the form of aerated cement paste. Figure 1.2 provides a visual comparison of two different types of LAC with a structural LC. LAC is characterized by defined voids between the aggregates, which remain within the structure after compaction (Figure 1.2b). These voids are intentionally created by limiting the cement paste content to the minimum required to bind the aggregates at their points of contact. While there is no

standardized definition for the minimum pore volume needed to categorize a concrete as "open porous," it's often assumed to have a planned pore volume of about 10% by volume, which is the upper limit for structural concrete when an air-entraining agent is added (known as LP concrete). Consequently, the distinction must be based on the volumetric mix design.

A recent type of lightweight concrete was initially developed for a non-building industry application, specifically for sandwich ship hulls. The concept involved using sandwich plates consisting of steel skins with a very low-density lightweight concrete as the core material for ship and marine structure design. This lightweight concrete type was adopted by Schlaich and termed "infra-lightweight concrete" (ILC), representing a non-standardized lightweight concrete. ILC is characterized by a dry density of less than  $800 \text{ kg/m}^3$  and a compressive strength equal to or less than LC8/9. ILC results in a fair-faced concrete surface and allows for the creation of monolithic external concrete walls without the need for additional insulation. Its compacted structure more closely resembles that of LAC with a porous matrix (aerated cement paste) (Figure 1.2c) than traditional LC. So far, the standards for structural concrete have been used for designing ILC, with design rules extrapolated to lower densities, achievable through project-related approvals. New initiatives are currently underway at Universität der Bundeswehr München in collaboration with various industrial partners. The core idea involves combining the original design concept of ILC with the technical regulations outlined in EN 1520. The current challenge lies in establishing on-site conformity rules, already a part of a project-related approval, with the aim of eventually transitioning into a European technical approval (ETA).

## SCOPE OF THE STUDY

The scope of this study is all-encompassing, focusing on the design and evaluation of lightweight concrete walls, with a set of well-defined objectives guiding the research. Firstly, the study embarks on a thorough exploration of various lightweight composite materials, such as carbon fiber, fiberglass, and advanced polymers. This assessment will consider their mechanical properties, cost-effectiveness, and potential for weight reduction, ultimately aiding in the selection of the most suitable materials for specific applications. In parallel, innovative design methodologies will be developed to optimize the structural efficiency of lightweight concrete walls. These methods will aim to achieve the desired performance outcomes while minimizing the use of materials and reducing weight,

contributing to enhanced fuel efficiency, energy savings, and improved mobility across diverse sectors.

To ensure the long-term reliability and safety of lightweight concrete walls, the study will rigorously assess their mechanical properties, strength, and durability through comprehensive testing, simulations, and modeling. This will involve load-bearing tests, impact resistance assessments, and fatigue testing under real-world conditions. Environmental considerations are paramount, and the study will evaluate the impact of lightweight composite materials and structures on the environment. This evaluation will encompass factors such as recyclability, reduced emissions during production, and the potential for sustainable manufacturing practices.

Manufacturability and scalability are critical aspects, and the study will address challenges related to cost-effective and efficient manufacturing techniques for producing lightweight concrete walls. This includes considerations related to fabrication, assembly, and quality control. In addition, the study will perform in-depth cost-benefit analyses to ascertain the economic feasibility of lightweight composite walls in comparison to traditional materials. This analysis will encompass factors such as material costs, production efficiency, and potential maintenance savings. Exploration of innovative applications for lightweight composite walls across various industries, including aerospace, automotive, renewable energy, and construction, will be conducted to expand their utility and advantages.

Regulatory compliance is essential, and the study will ensure that lightweight composite walls meet industry-specific regulations, safety standards, and certification requirements to guarantee their suitability for critical applications. Finally, knowledge dissemination is a crucial component of the study's scope. The research findings, best practices, and design guidelines will be shared through publications, conferences, and industry collaborations, contributing to the advancement of the field of lightweight composite structure design and performance evaluation. In summary, the study's scope is both comprehensive and focused, with a holistic approach to the design and evaluation of lightweight concrete walls, driven by a set of well-defined objectives that span material selection, structural efficiency, environmental impact, sustainability, production, cost analysis, applications, regulatory compliance, and knowledge sharing.

## STATEMENT OF PROBLEM

Sustainability and the environmental impact of lightweight composite materials and structures are of growing concern. It is crucial to assess their influence on sustainability, encompassing factors like recyclability, emissions during production, and the adoption of sustainable manufacturing practices. The study also delves into the realm of manufacturability and scalability, seeking cost-effective and scalable manufacturing techniques for producing lightweight concrete walls. This encompasses addressing issues related to fabrication, assembly, and quality control. Ensuring the long-term strength and durability of lightweight concrete walls is paramount to guarantee their reliability and safety in practical applications, requiring rigorous testing and assessment. Economic feasibility is a significant challenge. Comprehensive cost-benefit analyses must be conducted to determine whether lightweight composite walls are economically viable when compared to traditional materials. Material costs, production efficiency, and potential maintenance savings all need careful consideration.

Regulatory compliance and safety standards are another critical aspect. Ensuring that lightweight composite walls adhere to industry-specific regulations and certification requirements is essential to ensure their suitability for various applications. Exploring innovative applications for lightweight composite walls in industries such as aerospace, automotive, renewable energy, and construction is a vital endeavor to unlock their full potential. The dissemination of research findings, best practices, and design guidelines is a key objective. Effective knowledge sharing is crucial for the advancement of the field of lightweight composite structure design and performance evaluation. The study seeks to tackle a diverse range of challenges and concerns to facilitate the effective design and evaluation of lightweight concrete walls, with a focus on sustainability, safety, and suitability for a wide spectrum of applications.

## RATIONALE OF THE STUDY

The rationale for conducting the study on lightweight concrete walls design and evaluation is compelling and multifaceted. In a world increasingly conscious of sustainability and environmental impact, lightweight materials have gained prominence in the construction industry and various other sectors. Lightweight concrete walls have emerged as a promising solution with the potential to significantly reduce energy consumption, lower emissions, and promote sustainable manufacturing practices. This study seeks to address several critical aspects: Economic viability is a pressing concern in today's

global landscape. Therefore, a comprehensive exploration of the economic feasibility of lightweight concrete walls, in comparison to traditional construction materials, is of paramount importance. This analysis is expected to shed light on potential cost savings and efficiency gains associated with the use of lightweight materials.

Furthermore, the study is driven by the pursuit of innovation in materials and design methodologies. Lightweight concrete walls provide a platform for the development of new lightweight composite materials and the exploration of innovative design techniques. Maximizing structural efficiency while minimizing weight is a key objective, with potential implications for various industries. Safety is a non-negotiable aspect, particularly in critical applications such as aerospace and automotive. Ensuring compliance with stringent safety standards and industry-specific regulations is an imperative goal of this research, reinforcing the suitability of lightweight concrete walls for diverse applications. Performance and long-term durability are fundamental considerations. Lightweight materials must not only meet but exceed performance expectations and demonstrate their reliability in real-world scenarios. Rigorous testing and assessment are essential components of this endeavor.

The applications of lightweight concrete walls span various industries, from construction and renewable energy to aerospace and automotive. Identifying new and innovative applications expands their utility and economic potential, contributing to enhanced energy efficiency and mobility. Furthermore, knowledge dissemination is a vital aspect of this study. Sharing research findings, best practices, and design guidelines within the industry fosters innovation and the adoption of best practices, driving the field of lightweight composite structure design and performance evaluation forward. The rationale for this study is founded on the potential benefits of lightweight concrete walls, ranging from sustainability and cost-effectiveness to safety and innovation. It addresses a range of critical issues, from environmental impact to economic feasibility, with the ultimate goal of advancing the understanding and application of lightweight materials in construction and various other sectors.

## REVIEW OF LITERATURE

Design and evaluation of lightweight concrete walls have been a topic of interest in the construction and building industry for several decades. This literature review will provide an overview of key

research findings and developments in this field under this section through the following heads,

### LIGHTWEIGHT CONCRETE MATERIALS

Lightweight concrete is not a recent innovation but has a historical lineage dating back to ancient times, with the famous Pantheon in Rome (built around 128 A.D.) serving as a testament to its early use. However, its widespread use waned after the Roman Empire due to limited access to natural lightweight aggregates (Lamphrechet, 1996). The renaissance of lightweight concrete came with the advent of industrially produced lightweight aggregates in the 19th and 20th centuries (Chandra, 2002). Military applications played a pivotal role in the material's resurgence. Lightweight aggregates were initially reserved for the U.S. Navy during World War I, primarily for shipbuilding, which ultimately facilitated the material's adoption in structural engineering (Holom, 1980). The establishment of the first commercial plant for producing expanded aggregates in 1920 marked a significant turning point, as industrially produced aggregates offered consistent quality and composition, outperforming their natural counterparts (Raithby, 1981).

Structural applications expanded with the use of expanded slate as an aggregate in lightweight concrete for bridges in the 1920s. This laid the foundation for a growing number of lightweight concrete bridges in the United States and Canada. In the mid-20th century, lightweight concrete became a common choice for constructing multi-story high-rise buildings (Thienel, 2007). Global energy concerns in the wake of the 1973 oil crisis prompted reevaluations of energy consumption policies. For example, Germany implemented the Energy Saving Act, raising thermal insulation requirements for building exterior walls (Bundesregierung, 1977). Since the 1990s, changes in building regulations and advances in technology and science have led to a resurgence of interest in lightweight concretes, particularly in Europe. The focus is now on reducing concrete density while maintaining strength, and there's a growing preference for monolithic structures made of fair-faced lightweight concrete. Today, designers opt for massive lightweight concrete walls to achieve individual and easily shaped architectural designs. Lightweight concrete offers an array of advantages, including low density, favorable building physics, high fire resistance, and excellent durability. This historical journey showcases lightweight concrete's enduring legacy and its contemporary applications in energy-efficient

construction and architectural flexibility (Cavelline, 2017).

International standards such as EN 13055, ASTM C330M, ASTM C331M, and ASTM C332 play a pivotal role in specifying the characteristics and applications of lightweight aggregates (LWA). These standards are designed to ensure the quality and suitability of LWAs for use in various forms of lightweight concrete. EN 13055, a European standard, encompasses LWAs from diverse sources, categorizing them as natural, manufactured from natural materials, produced from industrial by-products, or derived from recycled source materials. This broad scope allows for versatility in lightweight concrete applications. In contrast, ASTM standards have a more specific focus. ASTM C330M addresses LWA for structural lightweight concrete, detailing their preparation methods, which can include expanding, pelletizing, or sintering materials such as blast-furnace slag, clay, diatomite, fly ash, shale, or slate. On the other hand, ASTM C331M concentrates on LWA for masonry lightweight concrete, emphasizing the processing of natural materials like pumice, scoria, or tuff. Both EN 13055 and ASTM standards underscore the importance of clear definitions and categorizations to ensure the consistency and reliability of LWA in concrete applications. These standards provide essential guidelines that help maintain the structural integrity and performance of lightweight concrete, contributing to the overall quality and safety of construction projects (Thienel, 2020).

## PROPERTIES AND PERFORMANCE OF LIGHTWEIGHT CONCRETE WALLS

The production of lightweight aggregate concrete involves various types of lightweight aggregates originating from different sources.

- **Natural Materials:** Lightweight aggregates can be sourced from natural materials such as volcanic pumice. These naturally occurring materials provide an inherent lightweight quality to the concrete.
- **Thermal Treatment of Natural Raw Materials:** Some lightweight aggregates are produced by subjecting natural raw materials like clay, slate, or shale to thermal treatment. An example of this is Leca, a lightweight aggregate that is created through the expanded clay process.
- **Manufacture from Industrial By-Products:** Lightweight aggregates can also be manufactured from industrial by-products like fly ash, as seen in the case of Lytag. This approach promotes sustainability by utilizing waste materials in construction.

- **Processing of Industrial By-Products:** Another method involves processing industrial by-products like pelletized expanded slab, which leads to aggregates such as Pellite.

The choice of lightweight aggregate depends on the specific requirements of the concrete. For instance, if high thermal insulation properties are the primary concern rather than structural requirements, a lightweight aggregate with lower strength characteristics may be selected, resulting in relatively low-strength concrete (Awang, 2013). Foamed concrete is another noteworthy option in the realm of lightweight construction materials. It is a highly workable, low-density material that can incorporate a significant amount of entrained air, often up to 75%. Foamed concrete is self-levelling, self-compacting, and can be easily pumped. It finds applications in filling voids, such as disused fuel tanks, sewer systems, pipelines, and culverts, especially in situations where access is challenging. Its good thermal insulation properties make it suitable for sub-screeds, filling under-floor voids, and insulation on flat concrete roofs (Othuman, 2011).

Moreover, lightweight aggregate concretes can be used for structural applications, offering strengths equivalent to normal weight concrete. The benefits of using lightweight aggregate concrete include a reduction in dead loads, improved thermal properties, enhanced fire resistance, and savings in transportation and handling of precast units on-site. It also reduces the need for extensive formwork and propping. The Eurocode 2 Part 1-1 provides design guidelines for lightweight concrete, with specific rules in section 11 addressing lightweight aggregate concretes. Concrete is classified as lightweight if its density is not more than 2200 kg/m<sup>3</sup>, while the density of normal weight concrete falls between 2300 kg/m<sup>3</sup> and 2400 kg/m<sup>3</sup>. Lightweight concrete can be specified using the notation LC for the strength class, denoting a lightweight concrete with specific strength characteristics (Lee, 2014).

However, it's important to note that lightweight concrete differs from normal weight concrete in terms of tensile strength, ultimate strains, and shear strengths, which are generally lower. Lightweight concretes are also less stiff, but the reduced self-weight compensates for this effect, leading to a slight reduction in the depth of beams or slabs. Creep and shrinkage characteristics of lightweight concrete are higher compared to normal weight concrete, which should be considered in the structural design.

Batching of lightweight concretes is typically performed by ready-mixed concrete producers. At lower workabilities, the concrete can be easily placed by skip or chute. Pumping is possible but requires careful attention to prevent the mix from separating, typically achieved with the use of admixtures. Over-vibration can lead to segregation, so flowing concrete is preferred when pumping is involved. In addition to traditional lightweight concrete, there is a specialized category known as autoclaved aerated concrete (AAC). First produced in Sweden in 1923, AAC has since found global application in various construction systems, including masonry units, reinforced floor/roof and wall panels, and lintels. AAC is known for its versatility, being easily sculpted, sawn, and penetrated by fasteners. It has gained popularity for its performance in different climatic conditions and remains a prominent choice in the construction industry. Lightweight concrete walls, owing to their unique properties and performance characteristics, hold a significant place in contemporary construction (Real, 2016). These features, which arise from the careful selection of materials and construction techniques, provide a range of advantages. Notably, lightweight concrete walls are celebrated for their excellent thermal insulation properties, creating an effective barrier against heat transfer. This feature translates into energy efficiency and reduced heating and cooling costs for buildings.

Additionally, these walls are known for their high fire resistance, providing crucial safety in the event of a fire. Their sound insulation capabilities, arising from the porous nature of lightweight aggregates, make them ideal for noise control in various environments, such as residential and commercial buildings. Durability is another key strength. Lightweight concrete walls can withstand exposure to harsh environmental conditions, including moisture and freeze-thaw cycles, ensuring that the structure maintains its integrity over the long term. This durability is often sought after in construction projects to ensure that the building's structural components remain reliable and long-lasting. Furthermore, these walls often offer versatility in design and shaping. Architects and designers can easily mold and shape lightweight concrete, resulting in structures that are not only functional but also aesthetically pleasing. This design flexibility has been instrumental in creating visually appealing and unique architectural designs (Zarief, 2010).

In some cases, lightweight concrete walls can serve as both structural elements and insulating layers, simplifying construction and enhancing energy

efficiency. This integrated approach reduces the need for additional insulation materials and streamlines the building process. Lastly, these walls contribute to sustainability, as the use of lightweight aggregates, including recycled and industrial by-products, reduces the environmental impact. By reducing the demand for virgin materials and decreasing waste, lightweight concrete walls align with eco-friendly construction practices and the growing emphasis on sustainable building methods. Lightweight concrete walls offer a multitude of advantages, including thermal insulation, fire resistance, sound insulation, durability, design flexibility, and sustainability. These properties and performance characteristics make them a versatile and practical choice in construction, particularly for projects where energy efficiency, safety, and design aesthetics are paramount (Suraneni, 2016).

### DESIGN CONSIDERATIONS FOR LIGHTWEIGHT CONCRETE WALLS

The definition of lightweight concrete can vary, resulting in a lack of precision when referring to this material. Different standards and guidelines provide various criteria for lightweight concrete based on factors like strength, density, and specific types. For example, the American Concrete Institute (ACI) 213R-14 "Guide for Structural Lightweight-Aggregate Concrete" specifies that structural lightweight concrete (SLC) should have a minimum cylinder strength of 17 MPa, with an equilibrium density ranging from 1120 to 1920 kg/m<sup>3</sup>. For specified density concrete (SDC), there is no strength requirement, and the equilibrium density can vary from 800 to 2240 kg/m<sup>3</sup>. Additionally, SLC with a compressive strength of 40 MPa at 28 days is considered high-strength lightweight concrete.

In Europe, structural lightweight concrete (LC) is covered by the material standards in EN 206, with its application regulated in EN 1992. The minimum strength class for LC is LC8/9, which refers to a characteristic cylinder strength of 8 MPa and a characteristic cube strength of 9 MPa. The design standard requires a minimum strength class of LC12/13. However, for strength classes LC70/77 and LC80/88, which are less commonly used due to limited practical experience, technical approval is mandatory in Germany. LC is characterized by an oven-dry density ranging from 800 to 2000 kg/m<sup>3</sup>, divided into density classes with a span of 200 kg/m<sup>3</sup>. It's important to note that LC can have a dense cement matrix, and its surface may closely resemble that of normal weight concrete (NC), with lightweight aggregates only becoming visible on a damaged or cut surface (DIN 2013).

This diversity in definitions and standards reflects the different applications, requirements, and regional preferences for lightweight concrete. It underscores the importance of precisely specifying the type of lightweight concrete under consideration in any construction project.

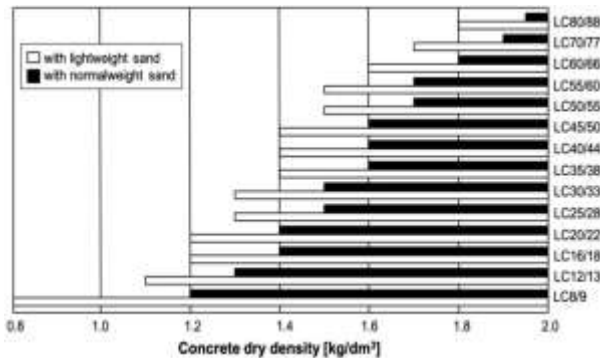


Figure 2.1: Dry Density of concrete (Source: Thienel, 2019)

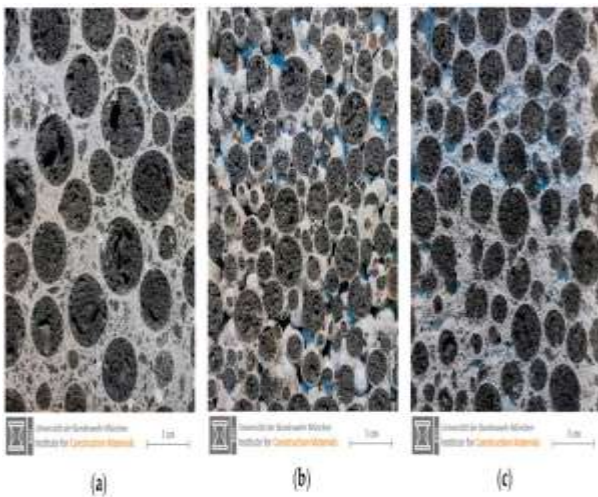


Figure 2.2: (a) Image of structural lightweight concrete (LC) with a dense matrix structure; (b) Image of the lightweight aggregate concrete (LAC) with open pore structure; (c) Image of LAC with a porous matrix filling the open pore structure. All three types of lightweight concrete are based on expanded clay from one producer as LWA. (Source: Thinele, 2020)

Lightweight aggregate concrete with an open structure, denoted as LAC, represents a distinct category that differs significantly from conventional lightweight concrete (LC). The properties and specifications of LAC are defined in EN 1520. Notably, LAC exhibits a dry density ranging from 400 to 2000 kg/m<sup>3</sup> and is divided into strength classes, namely LAC 2 to LAC 25, based on the characteristic strength of 100-mm cores drilled from LAC elements. LAC finds applications in structural elements like loadbearing walls, roof elements, slabs, and beams, as well as non-structural components such as noise

barriers. A unique feature of LAC is its open structure, characterized by defined voids that persist within the structure after compaction. These voids are intentionally created by limiting the cement paste content to the amount required to bind the aggregates at the contact points. Although there is no standardized definition for the minimum pore volume required to categorize a concrete as "open porous," a planned pore volume of approximately 10% by volume is often assumed. This volume aligns with the upper limit for structural concrete when air-entraining agents are added.

In addition to LAC, there is another specialized lightweight concrete known as infra-lightweight concrete (ILC), which was initially developed for non-building applications, such as sandwich ship hulls. ILC exhibits an extremely low dry density, typically less than 800 kg/m<sup>3</sup>, and its compressive strength is less than or equal to LC8/9. ILC delivers a fair-faced concrete surface and enables the creation of monolithic external concrete walls without the need for additional insulation. Its structure after compaction aligns more with LAC, featuring a porous matrix of aerated cement paste. Traditionally, the standards for structural concrete have been applied to the design of ILC, with design rules extrapolated to accommodate lower densities and specific requirements. This was often achieved through project-related approvals DIN EN 12390-2 (2019). Presently, new initiatives are underway at the Universität der Bundeswehr München in collaboration with various industrial partners. These initiatives aim to combine the initial design concept of ILC with the technical regulations specified in EN 1520 for LAC. The primary challenge lies in establishing on-site conformity rules, and this endeavor has already seen progress through project-related approvals. The goal is to develop a European technical approval (ETA) that can provide standardized guidelines for the use of such innovative lightweight concrete materials (Karamloo 2019).

## CHALLENGES AND LIMITATIONS OF LIGHTWEIGHT CONCRETE MATERIAL

### Advantages of Lightweight Concrete

Lightweight concrete has the following advantages as reported by Pravin (2022) for Daily civil:

- It minimizes the dead load of the building.
- It is simple to handle, which decreases the cost of transportation and handling.
- Enhances workability.



- Thermal conductivity is decreased with lightweight concrete.
- The use of lightweight concrete in the rooms where air conditioning is to be installed during the building's construction would result in good thermal comfort and decreased power usage.
- Stronger and more durable in comparison.
- When compared to regular concrete, it has high resilience to freezing and thawing.
- The use of lightweight concrete provides an outlet for industrial wastes such as fly ash, clinkers, slag, and so on, which cause problems in landfills.

#### **Disadvantages of Lightweight Concrete**

- Lightweight concrete is often particularly sensitive to the amount of water in the mix.
- Because of the porosity and angularity of the aggregate, placement and finishing are difficult, necessitating the use of experienced labor.
- In rare situations, cement mortar may separate the aggregates and cause them to float on the surface.
- To ensure the correct mixing of concrete, the mixing period is longer than that of standard concrete.
- Lightweight concrete is porous and has a low resistance.

#### **Applications of Lightweight Concrete**

- Because LWC has a low strength, it is utilized in the building of roof slabs, tiny houses with load-bearing walls, and so on.
- It is also employed in the construction of staircases, windows, and garden walls, among other things.
- This is utilized in the construction of partition walls in large buildings.
- These are formed into slabs and utilized as thermal insulators throughout the building.

#### **SUMMARY**

Lightweight concrete has a rich historical background, dating back to ancient Roman times, and its modern development has been influenced by the availability of lightweight aggregates. The advent of industrially produced aggregates marked a turning point, enabling the construction of innovative structures such as lightweight concrete ships during World War I and II, and the subsequent use of lightweight concrete in structural engineering. The literature review highlights various types of lightweight

concrete, including structural lightweight concrete (LC), lightweight aggregate concrete with open structure (LAC), and infra-lightweight concrete (ILC). Each type possesses distinct characteristics, density ranges, and applications. Structural lightweight concrete is used in a wide range of structural elements, while LAC is known for its open structure, and ILC is exceptionally lightweight, primarily used for applications like monolithic external walls.

The review also points out the existence of standards and regulations that define the properties and specifications of lightweight concrete, such as EN 206, EN 1992, and EN 1520 in Europe, and ACI 213R-14 in the United States. These standards help ensure the quality and performance of lightweight concrete in construction. Despite its many advantages, lightweight concrete does come with limitations. These include reduced compressive strength, potential durability issues, moisture absorption concerns, and fire resistance challenges. Additionally, the complexity of mix design and limited technical data can present obstacles. Cost considerations, handling of fragile lightweight aggregates, and regional variations in regulations further underscore the importance of careful planning and assessment when working with lightweight concrete. In light of these findings, the literature review reveals that lightweight concrete is a versatile and innovative construction material with the potential to address specific design and performance requirements in diverse construction projects. To harness its benefits effectively, a comprehensive understanding of the various types, properties, and potential challenges is essential. Addressing these challenges and leveraging the unique properties of lightweight concrete can lead to the successful implementation of this material in construction, offering energy efficiency, structural versatility, and sustainable solutions in various applications.

#### **METHODOLOGY**

#### **MATERIAL SELECTION**

A critical stage in the building is choosing an appropriate lightweight aggregate, particularly when taking into account the project's overall needs, structural performance, and insulating qualities. Shale, expanded clay, perlite, and lightweight synthetic aggregates are examples of common lightweight aggregates. It is necessary to confirm that the lightweight aggregate satisfies all applicable standards and requirements after selecting one that is appropriate. This guarantees that the content satisfies performance and quality standards recognized by the industry.

Depending on the area and the planned application of the lightweight aggregate, standards and specifications may change.

### Physical Properties

- *Density:* Ensure that the lightweight aggregate's density satisfies the required standards. This makes certain that the material offers the appropriate lightweight qualities.
- *Particle Size Distribution:* Make sure the aggregate's particle sizes fall within the proper range. In concrete or other applications, this is essential to obtaining homogeneity and the desired qualities.
- *Absorption Characteristics:* Check the aggregate's capacity to both absorb and hold water. Understanding how the material interacts with concrete mixtures and affects overall performance is crucial.

### Mechanical Properties

- *Strength:* Analyze the lightweight aggregate's flexural and compressive strengths. Ensuring the material is capable of withstanding the loads and stresses it can experience in building applications is crucial.
- *Durability:* Assess the aggregate's resilience to weathering, abrasion, and other environmental variables. Stability and long-term performance depend on durability.

**Chemical Composition:** Analyze the lightweight aggregate's chemical makeup. Determine whether parts may react adversely with other building materials or in particular conditions. By doing this, problems like alkali-silica reactions and other chemical incompatibilities are avoided.

**Testing Standards:** Ascertain that testing protocols follow accepted norms, like those set by ASTM or other organizations in other areas. It is more reliable and easier to compare results when standardized testing procedures are followed. The success and longevity of your project can be increased by choosing a lightweight aggregate that is appropriate for the job and confirming that it complies with all applicable criteria.

### MATERIAL PROPERTIES

When designing and building structures, it is essential to comprehend the material properties of lightweight aggregates, especially when it comes to how they affect the structural behavior of components

such as shear walls. A thorough understanding of these material properties is necessary to evaluate how lightweight aggregates affect the overall structural behavior of shear walls. The advantages of less dead load and better thermal insulation must be weighed against any potential drawbacks, such as a lower modulus of elasticity, by engineers. For the shear wall to efficiently include lightweight aggregates while meeting safety and performance criteria, proper design, testing, and adherence to pertinent regulations are necessary. Seismic concerns and local building rules should also be taken into account while designing a structure.

### STRUCTURAL DESIGN

Engineers follow established structural engineering norms and standards while conducting a thorough analysis and design procedure. The lower density of lightweight aggregates—like expanded clay or lightweight concrete—becomes an important factor to take into account when using them in construction. The goal of using lightweight aggregates is to reduce the structure's overall weight, which has benefits in some situations. Engineers must, however, consider this decreased density in their calculations to guarantee that the construction will remain stable, long-lasting, and compliant with safety regulations. Furthermore, it is critical to identify any differences between lightweight and conventional aggregates in terms of the modulus of elasticity and shear strength. Ensure that the structure is resilient and able to bear applied forces, this entails a careful assessment of material attributes. Engineers can efficiently build structures that meet the structural criteria for safety and performance while also utilizing lightweight materials by including these factors in their designs.

### MIX DESIGN

The process of "designing" a concrete mix involves choosing proportions for water, admixtures, cementitious ingredients, and fine and coarse lightweight aggregate when using lightweight aggregate to create lightweight concrete. The objective is to produce concrete with particular desirable characteristics and attributes. The required physical qualities, exposure circumstances, structural element dimensions, and the concrete's intended application all play a role in determining the mix design requirements. The quantity and qualities of the materials used, together with the techniques and surroundings employed during placing, finishing, and curing, all have a direct impact on the quality of the concrete. Keeping the ingredients as simple as possible can help

preserve control over the concrete mixture, as too many components might make handling more difficult.

In the case of lightweight concrete using lightweight aggregate, the mix design process follows a systematic approach to meet the desired requirements. Initially, the specific needs, such as strength and durability, must be identified. Subsequently, an appropriate lightweight aggregate is chosen based on project requirements and availability, as it provides reduced density while maintaining structural integrity. Modifications are made to the mix proportions to incorporate the lightweight aggregate, ensuring that the fresh concrete mix retains sufficient workability. It is crucial to optimize the cement content to achieve the desired strength without excess paste, which could lead to shrinkage and reduced cost-effectiveness. By taking into account elements like resistance to abrasion, chemical exposure, and freeze-thaw cycles, the mix design is assessed to make sure it satisfies the durability criteria for the particular application. Compressive strength testing is one of the laboratory tests used to evaluate the effectiveness of the lightweight concrete mix. Based on test results, the mix proportions can be changed to provide the finished lightweight concrete product with the appropriate qualities. To maximize the performance of lightweight concrete and to have a thorough grasp of concrete mix design, it is important to take into account the following definitions:

- **Water-Cement Ratio (W/C):** The ratio of water to cementitious material (the total amount of Portland cement plus additional cementitious material) in the concrete mixture is known as the "Water-Cement Ratio" (W/C).
- **Specific Gravity (S.G.)** is the mass of a specific volume of material divided by the mass of a water volume of the same volume.
- **Bulk Specific Gravity (Saturated Surface Dry)** is the mass of a volume of water equal to the entire volume of the material divided by the volume of the material with its permeable gaps filled with water. The combined volume of solid matter, permeable voids, and impermeable voids makes up the total volume.
- **Absolute Volume** of loose material is the real volume that the material's solid particles occupy. The following formula can be used to determine a material's absolute volume given its known weight and specific gravity:

$$\text{Absolute Volume} = \frac{\text{Mass of Loose Material}}{\text{SG} \times \text{Unit Weight of Water}} \quad (3.1)$$

- **Density** is the weight of a material with a known absolute volume; it is commonly stated in pounds per cubic foot. Any material's density is determined by multiplying its specific gravity by the weight of water in units of measurement. It can be calculated in terms of density as follows:

$$\text{Density} = \frac{\text{Mass of Loose Material}}{\text{Absolute Volume}}$$

(3.2)

- **Cementitious Factor** is the amount of cement plus additional cementitious material included in a unit volume of concrete. It is usually expressed in lb/yd<sup>3</sup>.
- **Free Water** is the amount of water in the mixture less the amount of water that the aggregates absorbed to attain a saturated surface-dry state.

## CONSTRUCTION METHODS

Lightweight concrete's strength and longevity are greatly influenced by its design; therefore, care should be taken when handling, placing, and curing the mix to guarantee consistent quality.

### Batching and Mixing

Cement and aggregates should always be mixed by weight. It is possible to batch components based on volume, such as admixtures and water. If needed, batching by weight enables quick and easy change of mix parameters. It is important to measure material quantities very precisely. For batching equipment to reduce segregation, materials should flow freely and unhindered. To make sure that the right amounts of each material are being batched appropriately, the weighing equipment should be inspected frequently. For lightweight concrete to be regular and homogeneous, proper mixing is necessary. Lightweight concrete mixed improperly will have lower strengths and more batch-to-batch variability. Overmixing can cause the aggregate to break down and will lower the output of a batching operation. The best time to mix a mixture is determined by several variables, including the type of mixer, its condition, speed, size of the charge, and material composition. Better quality control can be achieved by ready-mix operations through the use of trained workers and automated equipment.

Additionally, this kind of operation does away with the requirement for large-scale material storage on the construction site. The segregation of coarse aggregates should be minimized during the placing process by treating lightweight concrete properly. Although it should be dropped vertically, lightweight concrete shouldn't be left to fall freely for extended

periods. The lightweight concrete should be allowed to enter the forms at a vertical angle and gently. The proper handling, mixing, and placement of lightweight concrete should be taught to the construction workers on the job site. Training sessions should be held to make sure that teams are aware of the precise requirements needed to attain the required attributes of lightweight concrete. To provide construction workers with practical experience, the training program will include simulations and demonstrations. To guarantee that learned practices are consistently applied throughout the construction phase, hence reinforcing accountability and excellence, a monitoring and feedback structure will be implemented.

## QUALITY CONTROL AND TESTING

A final product inspection serves as the first step in quality control; however, quality is unaffected by this process. Sustaining quality improvements requires combining inspection with methods that reduce the factors that lead to substandard workmanship. By monitoring product deviations from quality standards and investigating the reasons behind them, quality control techniques find solutions. Tough manufacturing conditions and situations where the approach is unable to directly control every variable are examples of robust approaches in action. Through the use of quality control procedures, product attributes are kept within permissible limits and near goal values. The aforementioned discrepancies stem from fluctuations in the production procedure and the product's design's susceptibility to these fluctuations. Robust quality control techniques influence product design to reduce manufacturing process sensitivity. Even in cases where production fluctuations are significant and unpredictable, they guarantee that quality is maintained and minimize departures from goal values. It is possible to verify that the lightweight concrete satisfies design criteria through a variety of material testing techniques. While some of these tests need actual sampling from the completed slab itself, others are conducted on sample specimens of the same lightweight concrete mix that will be used for the slab. There are several non-destructive testing methods (NDT) that are available in addition to the destructive procedures that require taking a sample or core of the lightweight concrete to evaluate its strength. The following are some of the techniques,

### Compression Test

Lightweight concrete that has been hardened to its maximum strength under ideal circumstances is determined by the compressive strength of the material,

which is measured by the compression test. The compressive loads applied to lightweight concrete cylinders or cubes are increased until they break. Based on the cross-sectional area and the maximum load, the strength is determined and recorded. A specimen's size and form are two examples of variables that can impact the outcome of a compression test. This test's outcomes may also be impacted by the amount of friction at the specimen's two ends during compression.

### Flexural Strength Test

The tensile strength of an unreinforced lightweight concrete beam or slab is indirectly assessed by the flexural test. Put otherwise, it evaluates a slab's resistance to flexure or bending. The deflection, applied load, and crack patterns of a lightweight concrete sample beam are measured after it is loaded using a two- or three-point system. Flexural tests exhibit high sensitivity to specimen handling, preparation, and curing protocols.

### Water Absorption Test

A lightweight concrete specimen is extracted from drilled cores or molded in cylinders to assess a slab's vulnerability to water penetration. It is recommended to weigh and saturate the samples before the test. At various separations from the exposed surface, the absorption can be determined.

### Moisture Content Test

Tests for moisture content quantify the amount of moisture in hardened lightweight concrete. An excessive amount of moisture in the lightweight concrete can cause it to become weaker, lose its strength, and develop mold. For an accurate measurement of moisture content, either a relative humidity meter or a calcium chloride kit is needed. The precise amount of moisture in a lightweight concrete slab can be determined by using either equipment for testing.

Professionals with the necessary training usually do lightweight concrete testing in labs or on-site with specialized equipment. The test results serve as a guide for building decisions, a means of confirming conformity with industry standards, and an assurance of the durability and quality of lightweight concrete structures.

## JOINT DETAILING

When designing lightweight concrete applications next to regular concrete sections, joint detailing needs to be carefully considered to account for any potential differences in movement between the two materials. Compared to conventional concrete, lightweight concrete may react differently to loads and environmental factors due to its unique features. Strong joint detailing techniques must be used to solve this possible disparity. These techniques must provide regulated movement and avert unfavorable outcomes like cracking or misalignment. In this situation, using the proper joint fillers and sealants becomes crucial as a preventative step to lessen the effects of any potential differential settlements between the lightweight and conventional concrete portions. In addition to preserving the overall construction's structural integrity, these joint fillers and sealants also improve the longevity and functionality of the jointed sections. The project may efficiently control the dynamic interactions between various concrete sections by giving careful joint detailing and the application of appropriate materials a top priority. This will ensure a robust and long-lasting construction result.

#### **FIRE PERFORMANCE**

Generally, concrete functions well in fire, both as a material by itself and as an engineered structure. According to EN13501-1:2018, it has the greatest fire resistance classification (class A1). The fire categorization technique for building elements and construction products is outlined in EN13501-1:2018. Classified as A1, these materials meet all other classification requirements and are non-combustible. Class A1 is the combustibility classification for concrete. Concrete testing is not required to prove this fire classification because it was established by a European Commission directive. The ruling covers any concrete containing less than 1% of organic material by volume or weight, which includes the majority of concretes and screeds that contain typical levels of polypropylene fibers. Because normal concrete naturally resists fire, it usually doesn't need any additional fire protection which properties align with the properties of lightweight concrete too. It has a slow rate of heat transfer and is non-combustible, meaning it doesn't burn. Concrete guarantees that fire compartmentation is maintained, structural integrity is maintained, and heat shielding is dependable. Concrete can be utilized to reduce fire risk for the lowest initial cost and the least amount of continuing maintenance because of its inherent material qualities. Other materials are dependent on the rate of loss of combustion, fire safety engineering, or fire prevention.

Future modifications were as easy as replacing light fixtures, according to management protocols, and altering employee behavior.

#### **CONSTRUCTION SEQUENCING**

To guarantee a successful and effective building process, lightweight concrete's unique qualities must be carefully taken into account while planning the construction sequence. A detailed guide is provided below:

- **Understanding Lightweight Concrete Properties:** The unique qualities of lightweight concrete distinguish it from regular concrete. Its decreased density—achieved by utilizing aerating agents or lightweight aggregates—contributes to the structures' reduced total weight. This feature affects the structural load on foundations and supporting parts in addition to making material handling and transportation easier. Furthermore, lightweight concrete has better thermal insulation qualities, which improves construction energy efficiency. Compared to conventional concrete, its special composition changes the behavior of the structure, impacting parameters like modulus of elasticity and compressive strength. Comprehending these attributes is essential for proficient construction scheduling, guaranteeing that the material's features are utilized to their fullest potential in project design and implementation. When these characteristics are carefully taken into account, structures that are lighter and have certain performance advantages that are suited to the project's needs can be created.
- **Engage with Structural Engineers:** In the process of constructing structures using lightweight concrete, consulting with structural engineers is essential. The structural specifications and design factors for lightweight concrete components should undergo thorough evaluation through cooperation. Together, they handle aspects like load-bearing capacity, structural integrity, and longevity to guarantee that the design complies with building codes and safety standards. When evaluating how the special qualities of lightweight concrete affect the whole structural system, structural engineers are essential because they can provide valuable insights into potential changes or reinforcements. To meet project-specific performance standards and achieve a well-balanced and secure design, collaboration between structural engineers and construction teams is essential.
- **Establish Construction Phases:** For a construction project to be executed in an organized manner, it must be divided into discrete phases. This

entails defining duties including finishing, structural framing, and foundation construction. Construction teams may efficiently assign resources, prioritize work, and keep a planned timeline throughout the project by precisely outlining each phase.

- **Material Procurement and Delivery:** To prevent construction delays, it is essential to buy lightweight concrete supplies efficiently and to receive them on time. Planning this component includes locating trustworthy suppliers, precisely calculating material quantities, and setting up an efficient logistics system. By managing material procurement proactively, construction schedule delays are minimized and a continuous workflow is ensured.

- **Site Preparation:** Installing lightweight concrete components requires first preparing the work site. This includes preparing the site, erecting formwork, and making sure the foundation is sturdy. To successfully pour lightweight concrete and contribute to the overall stability and lifetime of the construction, adequate site preparation is necessary.

- **Integration with Other Experts:** Conflicts during construction must be avoided by efficient collaboration with various professionals, including plumbers, electricians, etc. To avoid any disturbances and to ensure that different construction components are integrated without sacrificing the special qualities of the lightweight concrete, they must make sure that their work is in complete harmony with the installation of the lightweight concrete.

- **Formwork Design and Construction:** Appropriate formwork design and construction are essential for providing support for lightweight concrete during placement. Formwork design must be adjusted in light of the concrete's decreased weight. The correct shaping and support required for lightweight concrete are ensured by well-designed formwork, which enhances the precision and caliber of the finished construction.

- **Mixing and Placement:** To achieve the required qualities, lightweight concrete must be mixed according to the manufacturer's instructions. Organizing the placement order maximizes consistency and efficiency. To place lightweight concrete, any special tools or methods should be carefully considered to ensure a regulated and efficient operation.

- **Curing Process:** For lightweight concrete to have the required strength and longevity, an appropriate curing procedure must be used. Construction teams must follow the right curing procedures to optimize the material's performance and endurance, taking into account the influence of decreased density on curing requirements.

- **Quality Control and Testing:** Testing lightweight concrete samples regularly is necessary to establish an extensive quality control plan. Complying with industry norms and design criteria ensures that the properties are safe and structurally sound when the project is finished.

- **Monitoring and Adjustments:** Real-time adjustments can be made to the construction process in response to site circumstances, material performance, and unforeseen obstacles through continuous monitoring. To avoid delays or quality compromises, proactive problem-solving makes sure that the building project stays on schedule.

## DOCUMENTATION

Keeping thorough records is necessary to ensure that lightweight concrete is implemented in building projects successfully. This includes:

- **Lightweight Aggregate Information:** Maintain thorough documentation of the lightweight aggregates that were utilized for the project. Provide facts on the supplier, the kind of aggregate, and any other particulars that are pertinent to the construction.

- **Mix Designs:** Keep track of the lightweight concrete mix designs, including the amounts of water, additives, and ingredients. With the use of this information, lightweight concrete with the required qualities can be produced consistently.

- **Construction Methodologies:** Keep a record of all the building processes you follow to install lightweight concrete. The building team can refer to this documentation, which also helps to ensure uniformity throughout the project.

- **Quality Control Measures:** Keep a record of the quality control procedures that were followed during building. This covers the procedures used for testing, the documentation from inspections, and any modifications done to guarantee that the lightweight concrete satisfies requirements.

- **Deviations from Original Design:** Document any modifications made to the original plan, together with a description of the changes and their justifications. The transparency of the project depends on this documentation, which makes it possible to comprehend the changes made during construction.

- **Justification for Modifications:** A detailed explanation should be given for any modifications or departures from the original plan. This covers elements like unforeseen site circumstances, differences in the materials, or modifications made to improve the overall performance or efficiency of the project.

Keeping thorough records of all paperwork not only helps with quality control and future analysis but also acts as a historical record of the construction process and a point of reference for comparable projects. It improves accountability, openness, and the capacity to draw lessons from the project's victories and setbacks.

## **MATERIALS AND PROPERTIES**

### **LIGHTWEIGHT AGGREGATE PROPERTIES**

Concrete blocks, structural concrete, and pavement are among the lightweight concrete products that are made with lightweight aggregate, a type of coarse aggregate. The lightweight aggregate that is used in concrete can have any shape—it might be angular, rounded, or cubic. Its workability can be directly impacted by its texture and shape. The construction industry uses a level of compressive strength of 3000-5000 psi to design strengths for cast-in-place, precast, or prestressed concrete. It is something that lightweight aggregate concrete (LAC) makes it simple to accomplish. The proportion of the mixture, the air content, the water demand, the density, and the moisture content of the lightweight aggregate all affect the density of lightweight concretes. With LAC, the structural concrete density is readily attained. It's also well known that lightweight concrete can keep a low density and absorb very little water. It is known to be either lower or equivalent to regular concrete. Additionally, it is quite saturated. Compared to other forms of concrete, structural lightweight concrete slabs, walls, and beams made with LAC are thought to have longer fire resistance times.

#### **Density**

Compared to conventional aggregates, lightweight aggregates usually have lower densities. This characteristic has a direct impact on the concrete's total density and the shear wall's structural weight. Any aggregate having a dry loose bulk density of less than 1200 kg/m<sup>3</sup> is commonly referred to as lightweight aggregate. Lower-density concretes, which are useful in lowering the self-weight of structures and also offer superior thermal insulation than normal-weight concrete, are made from lightweight aggregates. The cellular or very porous microstructure of the aggregate accounts for its low weight.

#### **Compressive Strength**

For design strengths of cast-in-place, precast, or prestressed concrete, the construction industry often

requires values of compressive strength between 3,000 and 5,000 psi, which LAC can easily provide. Structural stability depends on LAC's compressive strength. Adjustments in mix design and wall thickness may be required because they might be less than that of regular-weight concrete. With different mineral additive amounts, LWC can also be constructed for the minimum compressive strength of regular concrete.

#### **Modulus of Elasticity (MOE)**

An indicator of a material's stiffness or rigidity is its MOE. It is a measurement of the amount of deformation that concrete will undergo at a specific stress level. For evaluating the shear wall's deformation and stiffness, the modulus of elasticity is crucial. Compared to normal-weight aggregates, lightweight aggregates may have distinct elastic characteristics. For ultra-lightweight concrete, the modulus of elasticity ranges from 65,000 psi to 3 million psi, while for medium-weight concrete, it is 3 million psi.

### **CONCRETE MIX PROPERTIES**

#### **Water-Cement Ratio**

Concrete's density, drying shrinkage, and workability are all directly impacted by the W/C ratio. A number of variables, including the type of cement used, the environment, and the strength of the concrete, affect the appropriate W/C ratio. The W/C ratio typically falls between 0.4 and 0.6. Increased water-to-cement ratios make concrete mixes easier to work with, but they also make the concrete less durable and strong. Conversely, a lower W/C ratio produces concrete that is more robust and long-lasting, but it could be harder to work with and manage. In order to avoid problems with the concrete, such as shrinkage, cracking, and low strength, the water-to-cement ratio must be precise. Concrete that has too much water in it may bleed and segregate, making it weaker and less resilient. For the lightweight concrete to be workable, strong, and long-lasting, the correct W/C ratio must be maintained.

#### **Admixtures**

Concrete is enhanced by the addition of additives to increase its strength, durability, and workability. During the mixing phase, they are added to the concrete mix and become a crucial component of the finished product. The strength and longevity of the hardened concrete, as well as the set and hardening times, can all be altered with the addition of additives. Chemical substances called additives are added to

concrete to change its characteristics. They are employed to decrease the amount of water required for a particular workability, regulate setting time, boost strength, and enhance durability in addition to making fresh concrete more workable. Concrete is mixed with additives for a number of purposes. For instance, they can aid in lowering the quantity of water required in the mixture, which will lessen the permeability of the concrete and increase its strength. They can also be used to increase the mix's workability, which will make it simpler to finish and position. Admixtures can improve concrete's strength and durability in a number of ways. For example:

- Admixtures that minimize water requirements in the mix result in less permeability and more strength in the concrete.
- By adding tiny air bubbles to the mixture, air-entraining admixtures can increase the concrete's resilience to freeze-thaw cycles.
- Superplasticizers can lessen the amount of shrinkage that happens during the curing process by making the mix more workable without adding more water to it.

Admixtures can assist extend the life of concrete structures and lessen the need for repairs and maintenance by strengthening and durability of concrete. To get the intended effects, admixtures must be used at the proper dosage. Problems like severe bleeding, segregation, and decreased strength might result from overdosing. Reduced strength, extended setting periods, and poor workability can all be caused by underdosing.

### Curing Methods

Concrete's capacity to acquire strength and longevity is significantly influenced by curing. Curing entails maintaining the proper moisture and temperature conditions for extended periods, both at depth and close to the surface. It happens just after the concrete is placed and finished. A sufficient amount of moisture is present in properly cured concrete to support ongoing hydration, strength growth, volume stability, resistance to freezing and thawing, and resistance to abrasion and scaling. The following factors determine the duration of an appropriate cure period:

- Size and shape of concrete member
- Future exposure conditions
- Mixture proportions
- Ambient weather conditions

- Specified strength

For ambient temperatures above 40 degrees Fahrenheit, slabs on the ground (such as pavements, sidewalks, parking lots, driveways, floors, and canal linings) and structural concrete (such as bridge decks, piers, columns, beams, slabs, small footings, cast-in-place walls, and retaining walls) must cure for at least seven days. For lightweight concrete to have the appropriate strength and longevity, proper curing is essential. To attain its maximum strength and durability attributes, the mix design should guide the selection of the appropriate curing technique.

### SHEAR WALL DESIGN PROPERTIES

#### Shear Strength

Concrete's ability to withstand forces that would otherwise cause its internal structure to move against itself is known as its shear strength. Observing whether a force causes the object's layers to slide in a horizontal or vertical direction, can be assessed both horizontally and vertically. The concrete will split into sliding segments if the force is greater than its shear strength. This is comparable to compressive strength; the primary distinction is that shear forces act laterally, while compressive forces typically act axially. Concrete's shear strength is just as important as its compressive and tensile strengths in determining how long-lasting and force-resistant the material is. These elements are crucial in determining the structure's lifetime and quality. The shear strength of concrete is crucial in mechanical and structural engineering to guarantee the safe design of elements like bolts, columns, and beams. To improve their shear strength, these elements can also be reinforced. For example, stirrups can be used in reinforced concrete beams.

#### Flexural Strength

One indicator of concrete's tensile strength is its flexural strength. It is a measurement of an unreinforced concrete slab's ability to withstand bending failure. The *modulus of rupture*, or *Psi*, is used to express the flexural strength. As shear walls are made to withstand lateral loads like wind or seismic forces, flexural strength becomes an essential factor in guaranteeing the wall's structural integrity. Because lightweight aggregates are used to minimize density, lightweight concrete requires careful consideration of material qualities, mix design, and reinforcing techniques. To ensure that the flexural strength of lightweight concrete meets or surpasses stated requirements, engineers must comply with construction



norms and standards. The addition of suitable reinforcement, like steel bars or fibers, is essential for improving the material's resistance to bending pressures. To monitor and ensure the functioning of the lightweight concrete, thorough testing and quality control procedures are necessary throughout the construction process. To further achieve the required flexural strength and overall structural resilience of shear walls in the face of lateral stresses, careful consideration of building processes, including appropriate curing methods, is also necessary.

## JOINT DETAILING PROPERTIES

Selecting appropriate joint fillers and sealants for lightweight concrete is essential to guaranteeing the structure's longevity and performance, particularly in cases where there may be differences in movement between lightweight and normal-weight concrete parts. These are some of the joint detailing sealants:

- **Flexible Polyurethane Sealants:** These sealants are renowned for their adaptability to movement. They are proficient at managing joint movements that are both dynamic and static. It is appropriate for lightweight concrete applications and is specifically made to be used in concrete joints.
- **Silicone sealants:** Suitable for a range of joint applications, these sealants are resilient and flexible.
- **Polysulfide sealants:** They can accommodate movements in concrete joints because of their good flexibility and resistance to weathering.
- **Modified acrylic sealants:** Suitable for joint applications, they offer flexibility and adherence.
- **Hybrid Sealants:** These sealants blend the characteristics of silicone and polyurethane, for example. They provide good durability, flexibility, and adhesion.

## FIRE PERFORMANCE PROPERTIES

Concrete is among the building industry's greatest materials for resisting fire. It is categorized as an A1 material, the highest grade of fire resistance, under European Standards (EN 13501-1:2007-A1:2009). Concrete is considered to be among the most fire-resistant materials for three primary reasons: it is non-toxic, it is not combustible, and it has a low thermal conductivity. This indicates that it reacts with other compounds and transfers heat energy slowly. Because of this, concrete is among the safest and best materials for preventing structural fires. Because lightweight particles have special qualities, LAC can show distinct fire resistance traits from ordinary

concrete. Several aspects need to be taken into account while assessing LAC's fire resistance:

- **Type of Aggregate:** Both organic and inorganic lightweight aggregates are available. When it comes to fire resistance, inorganic lightweight aggregates like expanded clay, shale, or slate aggregates typically offer superior performance over organic materials. Wood and cork particles are examples of organic lightweight aggregates that can catch fire at lower temperatures, which could have an impact on the overall performance of the fire.
- **Density:** Generally speaking, LAC is less dense than regular-weight concrete. In a fire, a lower density could lead to a quicker temperature rise, but it could also mean less heat transfer through the material and less thermal conductivity.
- **Moisture level:** The moisture level of certain lightweight aggregates may be higher, and this moisture may have an impact on how the concrete reacts to fire. Water vapor released during heating can affect fire resistance in both favorable and unfavorable ways.

Fire resistance is frequently assessed using standardized fire testing techniques, such as ISO 834 or ASTM E119. In these tests, temperature rise, structural integrity, and insulating qualities are measured while specimens are exposed to controlled fire conditions. Based on testing, manufacturers may supply fire resistance data; it is important to review this information for the particular LAC product.

## CONSTRUCTION PROPERTIES

### Handling and Placement

The fundamental principles of ACI 304 and ASTM C 94 hold for both normal-weight and lightweight concrete. The producer of ready-mixed concrete or the aggregate supplier has developed protocols that must be followed when handling aggregates. Because the lightweight aggregate is absorbent, it must be prewetted to a homogeneous moisture content before the other concrete materials are added. The same methods that are used to transport regular-weight concrete can also be applied to lightweight concrete. Conveyor belts, pumps, and ready-mix vehicles are examples of this. The lightweight concrete should be efficiently transported to its placement location without appreciably changing its intended characteristics in terms of slump, air content, density, homogeneity, water-to-cementitious materials ratio, or any other aspect. At preconstruction meetings, the mode of transportation must be decided

upon, taking into account the ingredients and amounts of the mixture, the kind and accessibility of placement, the necessary delivery capacity, the location of the batch plant, and the meteorological conditions. The form of transportation that will allow you to receive high-quality concrete at the most reasonable cost should be chosen after carefully weighing these different conditions.

The methods for correctly placing lightweight concrete are mostly the same as those for placing normal-weight concrete. The primary focus when handling and arranging concrete is to prevent the separation of the mortar matrix and coarse aggregate. The following fundamentals must be met for a proper lightweight concrete placement:

- A workable mixture that satisfies quality and placement standards
- Equipment that can handle and put the concrete quickly
- Appropriate consolidation
- Proper workmanship.

Well-proportioned lightweight concrete mixtures typically take less work to pour, screed, and float than normal-weight concrete due to their reduced density. It is best to avoid overworking or overvibrating lightweight concrete. When riding trowels with float pans are used too soon, delamination problems on air-entrained weight and lightweight concrete floors have been documented. Too much modification may cause too much mortar to show through. Coarse lightweight aggregate may also rise upward in combinations when the slump is more than the recommended quantity.

### Bond Strength

Resistance to the reinforcing steel bars slipping out of the concrete is the definition of bond strength in reinforced concrete. One of the most crucial components of the reinforced concrete structure's performance, especially in terms of the processes and manner of failure, is this resistance to slippage. Tensile strength is a function of bond strength and is contingent upon the degree of bond strength between the mortar and coarse aggregate phases as well as their respective tensile strengths. Lightweight concrete has lower bond-splitting capacities and a lower post-elastic strain capacity than normal-weight concrete due to the lower particle strength. The performance and structural integrity of shear walls are significantly influenced by the strength of the bond between the lightweight concrete and the reinforcing components. Effective force transfer between the concrete and the

reinforcement during seismic events or other loading situations is ensured by proper bonding.

When evaluating bond strength in lightweight concrete shear wall construction, there are some important factors to take into account. To guarantee that the reinforcements and concrete are free of impurities, surface preparation is essential. It's critical to ascertain whether the reinforcement material, including the proper corrosion protection, is compatible with lightweight concrete. Achieving the desired performance requires adhering to specified concrete mix designs, which include lightweight aggregates, cementitious ingredients, and admixtures. Before placement, adhesion promoters or bonding chemicals should be applied to the concrete or reinforcing surfaces to improve the bond. To achieve the best bond strength and prevent situations that could cause premature drying, proper curing following industry standards is crucial. Realistic structural forces are simulated by using a variety of testing techniques, such as pull-out or beam tests, as outlined in standards such as ASTM C1583. Both during and after construction, environmental factors like as temperature and moisture variations must be taken into account. Enhancing bond strength in shear wall construction with lightweight concrete requires following best practices, making sure that lightweight concrete is properly consolidated around reinforcements, and putting in place strict quality control measures for materials, mix proportions, placement, and curing processes.

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