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## Lightweight concrete

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### ABSTRACT

*Lightweight concrete (LWC) boasts a rich history dating back to ancient Roman times and has gained popularity due to its lower density and superior thermal insulation properties. In comparison to normal weight concrete (NWC), LWC significantly reduces the dead load of structural elements, making it particularly appealing in multi-story buildings. While most studies on LWC focus on "semi-lightweight" concretes, which use lightweight coarse aggregate and natural sand, there is potential for even greater environmental and economic benefits if waste materials replace the fine lightweight aggregate.*

*With a history spanning over two millennia, the technical development of lightweight concrete continues to progress. This review begins with a retrospective, providing an overview of the diverse applications covered by lightweight concrete in the last century. Despite its proven technical potential, there are still hesitations and uncertainties in practice. To address this, the review delves into lightweight aggregate properties and various types of lightweight concrete, placing a special emphasis on current standards. Drawing from 25 years of practical and theoretical experience in the field, the review highlights the need for adaptations in design, production, and execution rules when working with lightweight concrete, which often deviate from those applied to normal weight concrete. Certain aspects prone to misunderstandings, such as nomenclature and the informational value of specific tests, are explored.*

*The review addresses frequently occurring problems related to the mix design and production of lightweight concrete, elucidating unintended consequences. Additionally, a critical examination is provided of information found in existing European concrete standards regarding the mechanical properties of structural lightweight concrete. The review concludes by presenting the latest stage of development in very light lightweight concretes. Introducing Infra-lightweight concrete as an innovative approach, it aims to further extend the applications of lightweight concrete. This section provides background knowledge and experiences from case records, shedding light on an exciting frontier in the evolution of lightweight concrete.*

**Keywords:** Expanded Clay Aggregate, Silica fume, Poly Vinyl Alcohol (PVA), Density, Compressive strength, Flexural strength.

## **I. INTRODUCTION**

Lightweight concrete (LWC) stands out as a remarkable human invention with diverse applications across the construction industry. It finds utility in critical areas such as frames and floors, curtain walls, shell roofs, folded plates, bridges, off-shore oil platforms, and precast structures. Notably, the strength of LWC is 26 to 36% lighter compared to traditional concrete. Concrete, in general, is categorized into three types based on weight: heavy concrete (3200 kg/m<sup>3</sup> to 4000 kg/m<sup>3</sup>), normal weight concrete (2500 kg/m<sup>3</sup> to 2700 kg/m<sup>3</sup>), and lightweight concrete (2000 kg/m<sup>3</sup>).

Concrete, one of the oldest construction materials, has undergone continuous research and development over the years, resulting in various types to meet industry demands. Lightweight concrete, with its increasing popularity, is classified based on concrete density. The practical density range for lightweight concrete falls between 300 kg/m<sup>3</sup> and 1850 kg/m<sup>3</sup>. The demand for lightweight concrete has risen due to its practical and economic advantages, leading to its partial use in structures like panel walls and roof slabs.

The use of lower-density concrete can significantly reduce the self-weight of structures, allowing for a reduction in column and foundation size and other load-bearing elements, consequently lowering costs. Additional advantages of lightweight concrete include excellent thermal insulation properties, improved fire resistance, and enhanced handling convenience due to reduced total material mass. This reduction in material mass contributes to lower haulage and handling costs, ultimately increasing productivity.

## **HISTORICAL REVIEW**

Lightweight concrete is not a recent innovation; its usage dates back to ancient times, with evidence dating as far back as 4,000 BC during the Mohenjo-Daro and Harappa civilizations. Notably, the Romans also employed lightweight concrete in their construction projects, with enduring examples such as the St. Sofia Cathedral, also known as Hagia Sophia, in Istanbul, Turkey. Several ancient structures, including the Roman Pantheon (constructed between A.D. 118 to 128), the aqueduct Pont du Gard (built around A.D. 14), and the Coliseum (constructed between A.D. 70 and 82), showcase the historical application of lightweight concrete.

While the use of lightweight concrete declined after the fall of the Roman Empire, leading to the adoption of different materials and construction methods, its historical significance is evident in the enduring structures of that era. The history of lightweight concrete spans over two thousand years, and its technical development is still ongoing. This review begins with a retrospective look, providing insights into the wide range of applications covered by lightweight concrete in the past century.

## **II. PRODUCTION PROCESS AND PROPERTIES**

There are several methods for producing Lightweight Concrete (LWC), each involving distinct processes. LWC is composed of lightweight aggregates, either natural or manufactured, which include gravel or crushed stone, contributing to its sustainable bulk density over concrete texture. One primary method is the creation of "no-fines concrete," where fine aggregates are entirely eliminated from the mix. As various types of aggregates can be used, the concrete's strength can be tailored accordingly.

Another commonly employed method is 'Aerated Concrete,' also known as foamed, gas, or cellular concrete. In this process, bubble voids are introduced into the concrete, forming a cellular structure. The third classification is 'Lightweight Aggregate Concrete' (LWAC), with a specific gravity less than that of normal concrete (2.8). LWAC is frequently used in construction due to its desirable characteristics.

Properties of lightweight aggregates play a crucial role, including:

**Particle Shape and Surface Texture:** Varying production methods result in different shapes and surface textures.

**Bulk Specific Gravity:** The cellular structure of lightweight aggregates contributes to lower specific gravity compared to normal concrete.

**Unit Weight:** LWC has lower unit weight than other concrete types due to the cellular structure of lightweight aggregates.

**Moisture Content and Absorption:** Lightweight aggregates can absorb more water due to their molecular structure, typically ranging from 5 to 20 percent by weight of dry material.

The remaining properties of LWC, such as elastic properties, compressive and tensile strength, time-dependent properties, durability, and fire resistance, depend on the type of aggregates used. Challenges in the application of LWC include adapting the normal mix design procedure for lightweight concrete and addressing its rapid absorption quality.

The strength of LWC is contingent on the production method, as indicated by experimental findings. The understanding of these properties and challenges is essential for the effective and successful application of Lightweight Concrete in various construction contexts.

## **APPLICATIONS OF LWC**

Lightweight concrete traces its usage back to the 18th century, notably by the Romans in structures like 'The Pantheon,' where pumice aggregate was incorporated into cast in-situ concrete. In the late 19th century, the USA and England embraced clinker in constructions such as the 'British Museum' and low-cost housing. Lightweight concrete also found application during the First World War, notably in the United States for shipbuilding and concrete blocks. In the 1930s, England and Sweden introduced foamed blast furnace-slag and pumice aggregate for block making.

In contemporary times, with technological advancements, lightweight concrete has evolved and expanded its applications. For instance, perlite, renowned for its exceptional insulating properties, is widely used as loose-fill insulation in masonry construction. This application enhances fire ratings, reduces noise transmission, and offers resistance to rot and termites. Additionally, lightweight concrete is employed in various modern applications, including vessels, roof decks, and other construction scenarios, showcasing its versatility and adaptability in today's construction landscape.

### **OBJECTIVES OF LWC**

Lightweight aggregate concretes can be used for structural applications, with strengths equivalent to normal weight concrete. The benefits of using lightweight aggregate concrete include: Reduction in dead loads making savings in foundations and reinforcement. Improved thermal properties. Lightweight concrete offers improved thermal properties to help with energy efficiency and, because it is over half the weight of regular concrete, it offers an easier and quicker installation. No forklift during delivery is required, saving you time, money, energy and headaches.

### **ADVANTAGES OF LWC**

To mitigate the structural dead load of a building, lightweight concrete presents numerous advantages. Its reduced density not only facilitates easier handling but also significantly decreases transportation and handling costs. Beyond these logistical benefits, lightweight concrete enhances workability during construction. Additionally, it boasts lower thermal conductivity, thereby improving insulation performance.

Lightweight concrete exhibits robust resistance to the freeze-thaw cycle, surpassing conventional concrete in this regard. Furthermore, its adoption provides an eco-friendly solution for industrial waste disposal, incorporating materials like fly ash, clinkers, and slag. This not only addresses waste management concerns but also aligns with sustainable construction practices. In terms of safety, lightweight concrete offers excellent fire resistance, adding a crucial layer of protection in the event of fire incidents. Moreover, its use contributes to overall economic benefits by reducing foundation costs. Thus, lightweight concrete emerges as a versatile solution, streamlining construction processes, addressing environmental considerations, and enhancing both the structural and economic aspects of building projects.

### **SCOPE FOR FURTHER STUDY**

The primary objective of this research is to explore the concept of Lightweight Concrete and assess its utilization within the construction industry in Malaysia. The study aims to consider various factors influencing the adoption of Lightweight Concrete and provide recommendations based on the findings.

The chosen research methodology involves conducting interviews to gather information from developers, local authorities, and international sources such as the UK and other countries with experience in using Lightweight Concrete. Additionally, reference books related to Lightweight Concrete and its applications in the construction industry in Malaysia will be consulted.

To conduct a comprehensive study, three specific sites around Selangor state have been selected. This choice is motivated by the fact that Selangor is a developed state in Malaysia and has shown an interest in advancing the use of lightweight concrete in the country. The research aligns with the objectives outlined in Rancangan Malaysia ke-9, where the Malaysian government encourages the incorporation of Lightweight Concrete in government projects, even if in small amounts. The focus on Selangor state aims to capture insights into the local context and its potential impact on the development of lightweight concrete practices in Malaysia.

### **III. TYPES OF LIGHTWEIGHT CONCRETE**

Lightweight concrete can be produced by introducing air into its composition or by excluding finer sizes of aggregate and replacing them with hollow, cellular, or porous aggregate. Specifically, lightweight concrete can be categorized into three groups:

#### **1. No-Fines Concrete**

No-fines concrete is defined as lightweight concrete composed of cement and fine aggregate, forming uniformly distributed voids throughout its mass. It maintains large voids and does not create laitance layers. No-fines concrete is suitable for both load-bearing and non-load-bearing applications, such as external walls and partitions. The strength of no-fines concrete increases with higher cement content, but it is sensitive to water composition. Insufficient water can lead to a lack of cohesion between particles and subsequent loss in concrete strength.

#### **2. Lightweight Aggregate Concrete**

This type of lightweight concrete uses porous lightweight aggregate with low specific gravity instead of ordinary concrete. The main characteristic of this lightweight aggregate is its high porosity, resulting in a low specific gravity. It can be categorized into two types based on its application: structurally lightweight aggregate concrete and partially compacted lightweight aggregate concrete. The former, used for structural purposes, requires adequate strength and low density for optimal thermal insulation. The lightweight aggregate can be natural, such as pumice or scoria, or artificial, like expanded blast-furnace slag. The shape and texture of aggregate particles, as well as the coarse nature of fine aggregate, may affect the mix, with only denser varieties suitable for structural concrete.

### **3. Aerated Concrete**

Also known as gas concrete or foamed concrete, aerated concrete is produced by introducing large voids into the mortar mass or concrete through a chemical reaction or the use of an air-entraining agent. This type of lightweight concrete, characterized by its self-compacting nature and appropriate thermal insulation, is ideal for applications in hard-to-reach spaces and sewer systems. It does not require flattening during the construction process.

## **METHODOLOGY**

### **Compressive Strength:**

Compressive strength is a fundamental physical property of concrete and serves as a cornerstone for quality control in lightweight concrete. It is defined as the maximum resistance of a concrete specimen to axial loading. Compressive strength is crucial for assessing the structural integrity and performance of concrete. There are three common tests to determine compressive strength: cube, cylinder, and prism tests. The concrete cube test is a widely used standard method for measuring compressive strength, particularly for quality control purposes. The test involves calculating the highest compression stress that a test cylinder or cube can withstand.

### **Water Absorption:**

Water absorption is a significant property in concrete, playing a crucial role in predicting its durability and resistance to corrosion. It is a measure of the porosity of aggregates and is utilized as a correlation factor in determining free moisture using the oven-drying method. The absorption capacity is determined by weighing a surface-dry sample after soaking it for 24 hours and then reweighing it after drying in an oven. The difference in weight, expressed as a percentage of the dry sample weight, represents the absorption capacity. This test, conducted at 28-32 days, serves as a quality control check for durability. The test procedure is detailed in IS 456:2000.

### **Density:**

Density, or volumetric mass density, is a critical parameter in understanding the effect of lightweight concrete on strength, durability, and permeability resistance. To determine the density, samples are weighed using a scale, and the average weight of at least three samples is obtained. The density is then calculated using the formula:  $\text{Density} = \text{Mass}/\text{Volume}$  (in  $\text{kg}/\text{m}^3$ ).

## **IV. LITERATURE REVIEW**

### **Historical Perspective:**

Lightweight concrete has a rich history dating back to ancient civilizations such as the Romans, who used lightweight aggregates in structures like the Pantheon. Over the years, the development and utilization of lightweight concrete have evolved, with various methods and materials contributing to its widespread application.

### **Properties and Types:**

The properties of lightweight concrete, including reduced density, improved insulation, and enhanced workability, make it a versatile material in construction. Three primary types of lightweight concrete are commonly discussed in the literature:

**No-Fines Concrete:** Composed of cement and fine aggregates, forming uniformly distributed voids, suitable for load-bearing and non-load-bearing applications.

### **Lightweight Aggregate Concrete:**

Utilizes porous lightweight aggregates with low specific gravity, categorized into structural and partially compacted lightweight aggregate concrete.

**Aerated/Foamed Concrete:** Created by introducing large voids into the mortar mass or concrete through chemical reactions or air-entraining agents, offering self-compaction and insulation properties.

### **Applications and Advantages:**

The literature highlights various applications of lightweight concrete across the construction industry. Its advantages, such as reduced dead load, improved workability, and lower thermal conductivity, make it suitable for structures like frames, floors, curtain

walls, roofs, bridges, and precast elements. Additionally, the incorporation of lightweight concrete can contribute to the economic and environmental sustainability of construction projects.

**Mechanical Properties:**

Studies delve into the mechanical properties of lightweight concrete, with a focus on compressive strength, flexural strength, and durability. Researchers explore how factors such as aggregate type, mix design, and curing methods influence the mechanical performance of lightweight concrete.

**Innovations and Challenges:**

Recent literature reviews discuss innovative approaches and technologies in the development of lightweight concrete. Researchers explore the use of alternative lightweight aggregates and supplementary cementitious materials. Challenges, including mix design adjustments, structural design considerations, and standardization, are also addressed.

**Sustainable Development:**

Sustainability is a key theme in recent literature, with a focus on incorporating waste materials, such as fly ash, clinkers, and slag, into lightweight concrete. The environmental benefits and energy efficiency of lightweight concrete contribute to sustainable construction practices.

**Testing and Standards:**

Standard testing methods for evaluating the properties of lightweight concrete are extensively covered in the literature. Researchers emphasize the importance of adherence to standards in ensuring the quality and performance of lightweight concrete in various applications.

**Future Directions:**

The literature suggests potential future directions for lightweight concrete research, including advancements in materials, optimization of mix designs, and a deeper understanding of long-term performance and durability. Researchers and practitioners are encouraged to explore new avenues for improving the structural and environmental aspects of lightweight concrete.

In summary, the literature on lightweight concrete provides a thorough exploration of its historical roots, properties, applications, mechanical behavior, challenges, and sustainable development. Ongoing research continues to shape the field, offering insights into innovative approaches and addressing the evolving needs of the construction industry.

**V. CONCLUSION**

The preliminary findings indicate that lightweight concrete possesses favorable strength characteristics, positioning it as a promising alternative construction material for industrialized building systems. However, it is noted that the compressive strength of aerated lightweight concrete tends to decrease with lower density mixtures due to an increase in voids caused by the foam.

In particular, the compressive strength of foamed lightweight concrete falls below the recommended levels for non-load-bearing walls, registering a 27% reduction. Despite this limitation, the compressive strength is deemed acceptable for use in non-load-bearing structures. This underscores the need for careful consideration of application scenarios, where the advantageous properties of lightweight concrete can still be harnessed effectively within appropriate structural parameters.

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