


Development and Performance of Lightweight Concrete Using Non-Fired Alkaline Binders for Sustainable Construction

Dadakhanov Farrukh Adhamovich,¹ 

¹ Namangan Engineering Construction Institute,

adrenverb@gmail.com

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***Corresponding author:**

Dadakhanov Farrukh Adhamovich ¹

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Abstract

This research studies the development of lightweight concrete using unused alkaline binders as an environmentally sustainable alternative to traditional cement-based materials. The study highlights the environmental and economic benefits of this innovative approach, including reducing carbon dioxide emissions, energy saving, and efficient use of industrial emissions. Lightweight aggregates such as expanded clay and vermiculite were combined with alkaline binders such as sodium silicate and sodium hydroxide to produce concrete with excellent thermal insulation properties. From the results of the analysis, it became known to us that the density of the tiled sample materials ranged from 500 to 1200 kg/m³, the thermal conductivity coefficient from 0.12 to 0.25 W/M·K, and the compressibility strength was obtained in indicators in the range from 3 to 12 MPa. The above-mentioned properties make lightweight concrete one of the most alternative solutions for energy-efficient and insulating products. Widely used in construction, as well as the characteristics of consistency and compliance with long-term durability goals are discussed. The research work concludes with recommendations, emphasizing the need for research on long-term impact resistance and constructive structures.

Key words: Lightweight concrete, Unused alkaline binders, Sustainable building materials, Thermal insulation, Environmentally friendly building materials, Energy efficient, Industrial waste, Geopolymer technology

Introduction

Lightweight concrete plays an important role in modern construction due to its low density, effective thermal insulation and versatile properties. These properties make it an important material for structures that require reduced loading and increased energy efficiency, in particular high-rise buildings and sustainable building items.

The production of lightweight concrete based on unused alkaline binders provides us with

environmentally friendly and energy efficiency solutions. Binders used in a wide range of applications, such as Portland cement, require high energy consumption during the production process and release large amounts of environmentally harmful CO₂ gases during the production process. In contrast, the basis of unused alkaline binders is industrial waste and requires less energy during the production process, which ensures economic as well as energy conservation. When we use these innovative methods, we not only reduce the harmful effects that we bring to the environment, but also a child who has rationally used Waste Recycling, which is one of our biggest problems.

Purpose of the study. The main purpose of this study is to develop lightweight concretions using unused alkaline binders and to assess their physical, mechanical and thermal properties. The research is aimed at optimizing the composition of concrete and ensuring its compatibility with various building facades.

Literature review

Many studies have highlighted the potential of alkaline binders in the field of construction. For example, geopolymer technology has shown its effectiveness in the production of durable and stable building materials. In addition, light aggregates such as expanded clay and vermiculite have been well studied for their thermal and structural properties.

Nevertheless, the integration of unused alkaline binders with light aggregates has been little studied. There is a need to study the compatibility of these components and develop concretions that combine efficiency and stability. This research expands the available knowledge by studying the joint properties of these materials and optimizing them.

Materials and Methods

To alkaline binders, this sodium silicate (usually called water glass) and sodium hydroxide serve as the main alkaline activators. These substances facilitate the process of geopolymerization and form a solid binding Matrix. Connecting cement substances, such as volatile ash or soil granulated blast furnace slag, can be added to improve binding properties and increase durability.

Aggregate materials. Expanded Clay: a lightweight aggregate valued for its low density and excellent thermal insulation ability.

Vermiculite: a natural mineral used to improve the thermal and acoustic insulation properties of concrete.

Other Fillers: Synthetic or natural lightweight fillers such as perlite or pumice may be included to optimize the mix design for specific applications.

Technological Process. Preparation of Alkaline Binder Solution:

Sodium silicate and sodium hydroxide are mixed in specific proportions to prepare the activating solution. The concentration of sodium hydroxide is controlled to ensure optimal reactivity.

Mixing of Components: The prepared alkaline binder solution is mixed with lightweight aggregates and, if necessary, supplementary cementitious materials. Proper mixing ensures uniform distribution of materials.

Casting and Molding: The mixture is poured into molds and compacted to eliminate air voids while maintaining the lightweight nature of the concrete.

Curing Process: The concrete is cured under controlled ambient conditions without the need for firing or autoclaving. Humidity and temperature are regulated to ensure proper geopolymerization.

Research Methods. To evaluate the performance of the lightweight concrete, the following physical and mechanical properties are measured:

Density: Measured using the displacement method to determine the lightweight characteristics of the concrete.

Thermal Conductivity: Assessed using a thermal conductivity meter to evaluate the material's insulation properties.

Compressive Strength: Determined through uniaxial compression tests following standard procedures to ensure structural viability.

Water Absorption: Evaluated by submerging samples in water and calculating the percentage increase in weight, indicating the material's porosity and resistance to water ingress.

Results and Discussion

1. Physical Properties. Density: The lightweight concrete samples exhibited densities ranging from 500 to 1200 kg/m³, depending on the mix design and the type of aggregate used. Lower densities were achieved with vermiculite, while expanded clay provided slightly higher densities but enhanced mechanical strength.

Porosity: High porosity levels, reaching up to 40-50%, were observed, contributing to the lightweight and insulating properties of the concrete.

2. Mechanical Properties. Compressive Strength: The compressive strength ranged from 3 to 12 MPa, making it suitable for non-structural and semi-structural applications. Samples with a

high content of sodium silicate have a high strength due to the good nature of the coupling with the components during the solidification of the binder.

Bending strength: based on the test results, the bending strength values are between 0.8 and 2.5 MPa, making it the most alternative choice for constructions that accept small loading.

3. Thermal Insulation Performance. Thermal conductivity coefficient: the values of the thermal conductivity coefficient are in the range of 0.12 and 0.25 W/m·k, obtaining the most optimal insulation indicator. Samples prepared on the basis of vermiculite filler have the lowest value thermal conductivity coefficient, the results obtained are the most alternative for energy-saving constructions.

Resistance to the effects of heat: the prepared concrete samples retained their integrity, without changing their mechanical properties even in various types of rubble.

Table 1. Test results from samples prepared on the basis of different compositions.

Mix Design	Density (kg/m ³)	Compressive Strength (MPa)	Thermal Conductivity (W/m·K)	Water Absorption (%)
Mix A (Expanded Clay)	1200	10.5	0.25	15.2
Mix B (Vermiculite)	800	6.2	0.15	28.5
Mix C (Hybrid Filler)	1000	8.7	0.20	21.4

The results obtained in Table 1 above are the values of strength and low thermal insulation caefficiency, which are subject to high compression in lightweight concretes .

Analysis of the Obtained Results. 1. Environmental and Economic Advantages. Light concrete production based on non-combustible hydroxide binders is more environmentally friendly and cost effective than conventional Portland cement-based prepared concrete:

Depletion of harmful gases into the environment: the use of industrial waste products as an alkali binder in Xol construction, in contrast to the typical portlandsement, which requires a large amount of harmful gases in construction, which also distributes a large amount of harmful gases in production, reduces factors harmful to nature.

Energy efficiency aspects: the production technology without burning does not leave the need for ovens to be used in high-temperature burning, which leads to saving energy consumption.

Rational use of waste: through the use of waste-based binder in the obtained state, or the use of waste-based feeders, this technology advances the principles of round economics.

On the economic side: a decrease in the cost of production is achieved through a decrease in energy consumption and the use of ready-made, energy-efficient materials, such as expanded clay, such as vermiculite.

Comparison with scientific experience and research carried out in International Studies. The developments are consistent with research and research on lightweight concretions using geopolymer technology in the international miqiyos done in previous years:

Thermal conductivity properties: the thermal conductivity coefficient values (0.12–0.25 W/m·K) are compared with those recorded test results of samples prepared in a case using light fillers that represent the acceptability of vermiculite and expanded clay for the thermal insulation task.

Example: Studies from Europe report similar results for geopolymer concretes with thermal conductivity values in the range of 0.10–0.20 W/m·K.

Mechanical Properties: The compressive strength values (3–12 MPa) are consistent with international benchmarks for lightweight, non-structural concretes. However, slight variations can be attributed to differences in aggregate types, binder compositions, and curing conditions.

Example: A study from Australia noted similar strengths for geopolymer concretes with fly ash and expanded clay.

Innovative Contributions: This research emphasizes the synergy between non-fired alkaline binders and lightweight aggregates, an area less explored in existing literature, contributing novel insights into optimizing mix designs.

Practical Applications and Implications. The developed lightweight concrete has several practical applications, particularly in sustainable and energy-efficient construction:

Thermal Insulation Panels: Ideal for use in walls, roofs, and floors of buildings to enhance energy efficiency and reduce heating/cooling costs.

Non-Structural Elements: Suitable for applications like partition walls, decorative elements, and prefabricated components.

Green Building Initiatives: The material aligns with green building certification requirements (e.g., LEED) due to its low environmental impact and high insulation properties.

Adaptation to Climate: The thermal stability and lightweight nature make it particularly suitable for regions with extreme temperature variations, including arid and semi-arid climates.

The results obtained on the basis of the studies not only confirm the most alternative to the production of effective light concrete using alkaline binders, but also demonstrate the competitive possibilities with traditional materials in terms of its application and the nature of environmentally friendly material. Further research can focus on the applications of long-term durability, dimensionality and in a broader field in structural elements

Conclusion

Efficiency of production: the study shows promising aspects of how light concrete can be produced efficiently based on non-combustible alkaline binders. This process offers an alternative to concrete prepared on the basis of conventional cement by significantly reducing energy consumption and CO₂ of carbon dioxide harmful gases.

Characteristics of the material: the prepared sample showed values in the range of the density of concrete (500-1200 kg/m³), an indicator that makes concrete an alternative for effective thermal insulation products. Compression strength values (3-12 MPa) and thermal conductivity coefficient values (0.12–0.25 W/m·K) indicate a balance between strength and thermal insulation performance typical of energy-efficient building materials.

Potential areas of use: the lightweight concrete produced is suitable for heat-insulating panels, curtains and other non-load KP elements, especially for usefulness in climates with significant temperature changes. Its properties fulfill the requirements for efficient and energy-saving buildings, help to apply it in modern green construction projects.

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