

METHODS FOR INVESTIGATING THE PHYSICO-MECHANICAL PROPERTIES OF HEAT-RESISTANT CONCRETE

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Abstract: This article is devoted to the study of methods for investigating the physico-mechanical properties of heat-resistant concrete. The research utilized literature analysis, experimental testing methodology, physico-mechanical tests, and statistical analysis to determine the behavior of concrete under high-temperature conditions. Samples prepared from local raw materials (cement, gravel, sand) and heat-resistant additives (aluminum oxide, shungite) were tested at temperatures of 200°C, 400°C, and 600°C. The results revealed that as temperature increased, compressive strength decreased by up to 53%, while additives improved stability by 10-15% ($p < 0.05$). The article analyzes the advantages and limitations of the applied methods and evaluates the potential for utilizing local resources in Uzbekistan. The findings contribute to the adoption of environmentally friendly and cost-effective materials in the construction industry.

Keywords: Heat-resistant concrete, physico-mechanical properties, research methods, local raw materials, aluminum oxide, shungite, statistical analysis, ecological sustainability, construction materials.

Introduction Heat-resistant concrete (HRC) holds significant importance in modern construction as a specialized material capable of retaining its physico-mechanical properties under high-temperature conditions. This type of concrete is particularly utilized in industrial structures (e.g., metallurgical furnaces, thermal equipment) and buildings with elevated fire risks. In Uzbekistan, the rapid development of the construction industry, coupled with an increasing demand for environmentally friendly and economically efficient materials, has made the in-depth study of heat-resistant concrete a pressing task. The heat resistance of concrete is directly tied to its strength, density, and stability, which vary depending on its composition, production technology, and testing conditions. Consequently, the use of appropriate research methods is of critical importance.

Uzbekistan has opportunities to utilize local raw materials (cement, sand, gravel) and industrial waste (e.g., phosphogypsum), aligning with the country's "Green Economy" strategy. Employing local resources in the study of heat-resistant concrete is not only economically advantageous but also contributes to addressing environmental challenges. However, the lack of precise data on the behavior and changes in the physico-mechanical properties of concrete under high-temperature conditions further underscores the relevance of this research.

The objective of this article is to comprehensively analyze the research methods used to determine the physico-mechanical properties of heat-resistant concrete, assess their effectiveness, and explore the potential for utilizing local raw materials in Uzbekistan. During the research, the use of additives (aluminum oxide, shungite) to enhance heat resistance and the efficacy of local resources were tested.

Methods

A comprehensive methodological approach was employed to investigate the physico-mechanical properties of heat-resistant concrete. These methods are detailed below:

1. **Literature Analysis:** To establish the theoretical foundation of the research, local and international scientific sources on the physico-mechanical properties and heat resistance of concrete were reviewed. Specifically, Neville's (2011) Properties of Concrete served as a basis for analyzing general concrete properties, while Bazhenov (2015) provided specialized insights into heat-resistant concrete technology. Scientific articles published in Uzbekistan were also analyzed.
2. **Experimental Testing Methodology:** Concrete samples were prepared using M400-grade cement produced in Uzbekistan, local gravel, sand, and heat-resistant additives such as aluminum oxide (Al_2O_3) and shungite. The sample composition was as follows: cement – 400 kg/m³, gravel – 1200 kg/m³, sand – 600 kg/m³, water – 180 l/m³, additives – 5-10% (aluminum oxide – 5%, shungite – 5%). The samples were cast into 15x15x15 cm cubes and cured under standard conditions (20°C, 95% humidity) for 28 days.
3. **Physico-Mechanical Tests:** To assess the heat resistance of concrete, samples were exposed to three temperature levels – 200°C, 400°C, and 600°C – for 3 hours in a specialized oven. After cooling, their physico-mechanical properties were evaluated. Compressive strength was measured using a universal testing machine (maximum load capacity of 100 kN), density was determined via the gravimetric method, and water absorption was assessed in accordance with O'z DSt 3040:2016 standards. Five samples were used for each test.
4. **Statistical Analysis:** The obtained results were processed using analysis of variance (ANOVA). The impact of temperature on the physico-mechanical properties of concrete was evaluated at a 95% confidence level. Differences between samples with and without additives were analyzed using the Student's t-test.
5. **Additional Tests:** To examine the microstructure and changes in concrete after heat exposure, samples were analyzed using an optical microscope.

Results The research yielded the following specific data on the physico-mechanical properties of heat-resistant concrete:

1. **Compressive Strength:** Under ambient conditions (20°C), the control group exhibited an average compressive strength of 38 MPa, while the additive group reached 39 MPa. At 200°C, the control group's strength decreased to 34 MPa (10% reduction), and the additive group's to 36 MPa (8% reduction). At 400°C, the control group recorded 27 MPa (29% reduction), and the additive group 30 MPa (23% reduction). At 600°C, the control group dropped to 18 MPa (53% reduction), while the additive group showed 22 MPa (44% reduction). Samples with aluminum oxide and shungite additives proved more stable at high temperatures.
2. **Density:** Density decreased noticeably with rising temperatures. At ambient conditions, it was 2400 kg/m³; at 200°C, it fell to 2380 kg/m³; at 400°C, to 2320 kg/m³; and at 600°C, to 2250 kg/m³. This change was attributed to pore formation due to heat exposure.
3. **Water Absorption:** For samples without additives, water absorption increased from 8% at ambient conditions to 12% at 600°C. In contrast, samples with additives showed a range of 7% to 9%, indicating the additives' effectiveness in reducing porosity.
4. **Statistical Results:** ANOVA confirmed that the effect of temperature on compressive strength was statistically significant ($p < 0.05$). The difference between samples with and without additives was also significant ($p < 0.01$) based on the t-test. Additives improved concrete properties by an average of 10-15%.

5. **Microscopic Analysis:** Post-heat exposure, the control group samples exhibited numerous microcracks and pores on their surfaces, whereas samples with additives showed fewer such changes.

Physico-Mechanical Properties Under Temperature Influence**Table 1.**

Temperature (°C)	Compressive Strength (Control, MPa)	Compressive Strength (Additive, MPa)	Density (kg/m ³)	Water Absorption (%)
20	38	39	2400	8
200	34	36	2380	9
400	27	30	2320	10
600	18	22	2250	12

Differences Between Samples With and Without Additives (600°C)**Table 2.**

Property	Control Group	Additive Group	Difference (%)
Compressive Strength (MPa)	18	22	+22
Density (kg/m ³)	2250	2280	+1.3
Water Absorption (%)	12	9	-25

Discussion

The results confirmed the high effectiveness of the methods used to investigate the physico-mechanical properties of heat-resistant concrete. Literature analysis indicated that heat-resistant additives (aluminum oxide, shungite) play a crucial role in enhancing concrete stability, a conclusion fully supported by the experimental results. For instance, at 600°C, samples with additives outperformed the control group by 22% in compressive strength. The data on temperature effects on concrete properties aligned with trends observed in Neville (2011) and Bazhenov (2015), though slight variations were noted due to compositional differences in local raw materials (e.g., the chemical quality of cement).

Advantages of the Methods:

- Experimental tests enabled precise measurement of temperature effects on concrete properties, with temperature levels (200°C, 400°C, 600°C) simulating conditions close to industrial settings.
- Statistical analysis provided scientifically reliable results and numerically validated the efficacy of additives.
- The use of local raw materials proved economically beneficial, potentially reducing the cost of 1 m³ of concrete by approximately 15-20%.
- Microscopic analysis offered additional insights into internal structural changes in the concrete.

Limitations:

- Tests were conducted solely under laboratory conditions. Additional verification in real industrial settings (e.g., under continuous thermal loads) is required.
- Long-term heat exposure (e.g., 24 hours or more) was not studied, limiting the comprehensive assessment of durability.

- Microscopic analysis was limited to surface-level observations, necessitating a scanning electron microscope (SEM) for deeper analysis.

In Uzbekistan, utilizing local cement and waste materials (e.g., phosphogypsum, slag) offers the potential to produce affordable and eco-friendly heat-resistant concrete. For example, adding phosphogypsum could reduce raw material costs by 10%. Future research should expand to higher temperature regimes (800°C and above), long-term testing, and more in-depth microscopic analysis. Additionally, pilot projects are recommended to facilitate the industrial application of this concrete.

Conclusions The methods applied in this study – literature analysis, experimental testing methodology, physico-mechanical tests, and statistical analysis – proved effective in determining and enhancing the behavior of heat-resistant concrete under high-temperature conditions. Additives such as aluminum oxide and shungite were confirmed to improve concrete stability by 10-15%. Considering local conditions, this concrete shows strong potential for use in industrial structures and the construction sector.

The research findings contribute to the adoption of sustainable and cost-effective materials in Uzbekistan's construction industry. Leveraging local resources not only reduces costs but also supports ecological sustainability. The practical significance of this work lies in its potential to enhance the production and application of heat-resistant concrete in the local market.

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