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Performance and Applicability of Sulfur Concrete for Foundation Structures in Temperate Climate Conditions

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Abstract. The durability and serviceability of foundation structures in temperate climate regions are strongly influenced by seasonal temperature variations, moisture exposure, and groundwater conditions. Conventional Portland cement concrete used in foundations often exhibits limited resistance to prolonged moisture ingress and aggressive soil environments, which can reduce long-term performance. Consequently, the development and evaluation of alternative concrete materials with improved durability characteristics is of increasing interest in contemporary civil engineering research. This study examines the engineering performance and practical applicability of sulfur concrete as a foundation material under temperate climate conditions. Sulfur concrete is produced using modified elemental sulfur as a binder, eliminating the need for Portland cement and resulting in a dense, low-permeability composite. A comparative experimental investigation was conducted using sulfur concrete and conventional concrete of strength class B30 (C25/30), focusing on properties critical to foundation design. The experimental program evaluated compressive strength, water absorption, and freeze–thaw resistance. The results indicate that sulfur concrete achieved a higher compressive strength (42.8 MPa at 28 days) compared to conventional concrete of the same class (31.2 MPa). Water absorption of sulfur concrete was significantly lower (0.7%), demonstrating its high resistance to moisture penetration. In addition, sulfur concrete exhibited enhanced freeze–thaw durability, withstanding up to 300 cycles without observable structural damage, whereas conventional concrete showed degradation after 200 cycles.

INTRODUCTION

In recent years, the demands placed on building materials have increased significantly. In particular, the strength, durability, and environmental resistance of materials used for foundation structures are important factors. In temperate climates, seasonal temperature changes, precipitation, and groundwater exposure can lead to rapid erosion of foundations. Traditional Portland cement concretes often cannot provide sufficient stability in such conditions. Therefore, the search for concrete types based on alternative binding materials is becoming an urgent scientific issue. Sulfur concrete is one of such promising materials, which is made without the use of cement, but on the basis of modified sulfur.

The main purpose of this article is to scientifically substantiate the possibilities of using sulfur concrete in foundation structures in temperate climate regions and analyze its advantages.

EXPERIMENTAL RESEARCH

Materials and Mix Design

Physical properties: The experimental program was designed to evaluate the mechanical and durability-related properties of sulfur concrete in comparison with conventional Portland cement concrete for foundation applications in temperate climate conditions. Both concrete types were produced to meet the requirements of strength class B30 (C25/30), which is commonly used in foundation structures.

For sulfur concrete, modified elemental sulfur was used as the primary binder. The sulfur was thermally treated and stabilized to improve its structural performance and reduce brittleness. Natural river sand with a fineness modulus of 2.4 and crushed granite aggregate with a nominal size of 5–20 mm were used as fine and coarse aggregates, respectively. No cement or water was added to the sulfur concrete mixture.

The conventional concrete mixture was prepared using ordinary Portland cement (CEM I 42.5), natural sand, crushed granite aggregate, and potable water. The water-to-cement ratio was selected to ensure compliance with B30 strength requirements and adequate workability for casting foundation-related elements. Mix proportions for both concretes were optimized through preliminary trials to achieve comparable density and workability while maintaining distinct binder systems.

Specimen Preparation and Curing Conditions

Concrete specimens were cast in standard cubic molds with dimensions of 150 × 150 × 150 mm for compressive strength testing. For sulfur concrete, the molten sulfur binder was mixed with preheated aggregates to ensure uniform coating and proper compaction. The mixture was then poured into steel molds and allowed to cool and solidify at ambient laboratory conditions.

Unlike Portland cement concrete, sulfur concrete does not require water curing. Specimens reached their functional strength within 24 hours after casting. In contrast, conventional concrete specimens were demolded after 24 hours and cured in water at a temperature of 20 ± 2 °C for 28 days, in accordance with standard curing procedures. All specimens were visually inspected prior to testing to ensure the absence of surface defects or casting irregularities that could influence test results.

Compressive Strength Testing

Compressive strength tests were conducted at 28 days using a hydraulic testing machine with a loading rate consistent with international testing standards. The load was applied continuously until failure, and the maximum load was recorded for each specimen. For each concrete type, a minimum of three specimens were tested to ensure statistical reliability. The average compressive strength value was calculated and used for comparative analysis. Sulfur concrete specimens demonstrated a more brittle failure mode, while conventional concrete exhibited gradual cracking prior to failure.

RESEARCH RESULTS

Compressive Strength Results

The compressive strength of sulfur concrete and conventional concrete was evaluated for strength class B30 (C25/30) at the age of 28 days. The test results are presented in Table 1.

Table 1. Compressive strength of B30 concrete

Concrete type	Strength class	Compressive strength (MPa)
Conventional concrete	30	31,2
Sulfur concrete	30	42,8

As shown in Table 1, sulfur concrete achieved higher compressive strength compared to conventional concrete of the same class. The increase in strength was about 35–40%, which indicates that sulfur concrete can safely meet the structural requirements for foundation applications.

Water Absorption Results

Water absorption was measured to evaluate the resistance of concrete to moisture penetration. The results are summarized in Table 2.

Table 2. Water absorption of B30 concrete

Concrete type	Strength class	Water absorption (%)
Conventional concrete	30	6,1
Sulfur concrete	30	0,7

The water absorption of sulfur concrete was significantly lower than that of conventional concrete. This result shows that sulfur concrete has better resistance to water ingress, which is important for foundation structures exposed to groundwater.

Freeze–Thaw Resistance Results

The resistance of concrete to freeze–thaw cycles was evaluated to simulate the effects of seasonal temperature changes. The test results are shown in Table 3.

Table 3. Freeze–thaw resistance of B30 concrete

Concrete type	Strength class	Freeze–thaw resistance
Conventional concrete	30	F200
Sulfur concrete	30	F300

Sulfur concrete specimens remained stable after 300 freeze–thaw cycles, while conventional concrete showed surface damage after approximately 200 cycles. This indicates that sulfur concrete performs better under temperate climate conditions.

Summary of Comparative Results

To clearly compare the performance of both materials, the main results are summarized in Table 4.

Table 4. Comparison of B30 concrete properties

Property	Conventional concrete (B30)	Sulfur concrete (B30)
Compressive strength (MPa)	31,2	42,8
Water absorption (%)	6,1	0,7
Freeze–thaw resistance	F200	F300
Hardening time	7–28 days	1–2 hours

The results confirm that sulfur concrete shows better mechanical strength and durability compared to conventional concrete of the same strength class.

DISCUSSION

The experimental results obtained in this study provide clear evidence of the advantages of sulfur concrete compared to conventional Portland cement concrete when both materials are designed for strength class B30 (C25/30). The observed differences in mechanical and durability-related properties can be explained by the fundamental characteristics of the sulfur binder system and its interaction with aggregates.

The higher compressive strength of sulfur concrete is primarily associated with the dense and continuous matrix formed by the solidified sulfur binder. Unlike cement-based concrete, where strength development depends on hydration reactions and curing conditions, sulfur concrete gains strength through physical solidification. This results in a more uniform internal structure and reduced microcracking, which contributes to the increased load-bearing capacity observed in the tests. For foundation structures, this additional strength provides a greater margin of structural safety.

Water absorption results further highlight the suitability of sulfur concrete for use in foundations exposed to moisture and groundwater. The very low water absorption values indicate a limited pore network within the material. As a consequence, moisture penetration and capillary rise are significantly reduced. This behavior is particularly beneficial in temperate climate regions, where alternating wet and dry periods can accelerate the deterioration of conventional concrete through repeated moisture ingress.

The improved freeze–thaw resistance of sulfur concrete can be attributed to its low permeability and reduced internal water content. In conventional concrete, the presence of free water within pores often leads to internal stresses during freezing, resulting in surface scaling and microstructural damage. In contrast, sulfur concrete contains minimal absorbed water, which reduces the risk of frost-induced deterioration. This characteristic explains the higher number of freeze–thaw cycles sustained by sulfur concrete specimens without visible damage.

From a practical perspective, the rapid hardening behavior of sulfur concrete represents an additional advantage for foundation construction. The ability to reach functional strength within a short period allows for faster construction progress and reduced waiting times between construction stages. However, this feature also requires careful temperature control during production and placement, which should be considered in practical applications.

Overall, the discussion of the results confirms that sulfur concrete is a technically viable alternative to conventional concrete for foundation structures in temperate climate regions. Its superior strength, moisture resistance, and frost durability suggest that it can contribute to extended service life and reduced maintenance requirements, provided that appropriate production and handling procedures are followed.

CONCLUSIONS

This study investigated the feasibility of using sulfur concrete as a material for foundation structures in temperate climate regions, with a particular focus on strength class B30 (C25/30). The experimental results and subsequent analysis allow several important conclusions to be drawn regarding the mechanical performance and durability of sulfur concrete in comparison with conventional Portland cement concrete.

The results demonstrate that sulfur concrete provides higher compressive strength than conventional concrete of the same class. This indicates that sulfur concrete is capable of meeting structural requirements for foundation applications while offering an additional margin of safety. The strength development mechanism based on sulfur solidification, rather than cement hydration, contributes to the formation of a dense and uniform internal structure.

A significant advantage of sulfur concrete is its very low water absorption. This property greatly reduces moisture penetration and limits the negative effects of groundwater on foundation structures. As a result, sulfur concrete is particularly suitable for foundations exposed to humid soil conditions and seasonal moisture variations typical of temperate climates.

The freeze–thaw resistance results further confirm the durability potential of sulfur concrete. The ability to withstand a higher number of freeze–thaw cycles without visible damage suggests improved resistance to frost-related deterioration. This characteristic is especially important for foundations subjected to repeated temperature changes during winter and transitional seasons.

In addition to its mechanical and durability benefits, sulfur concrete offers practical advantages related to rapid hardening and reduced curing time. These features can contribute to shorter construction periods and improved efficiency in foundation works. However, careful control of production temperature and placement conditions is necessary to ensure consistent material performance.

In conclusion, sulfur concrete can be considered a technically reliable and durable alternative to conventional cement-based concrete for foundation structures in temperate climate regions. Its use has the potential to enhance service life, reduce maintenance requirements, and improve overall performance of foundation systems. Further research focusing on long-term field performance and large-scale applications is recommended to support wider implementation in construction practice.

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