University of Tabriz

Journal of Civil and Environmental Engineering
Volume 47 (2017), Issue 1 (Spring), 1-12.

EXTENDED ABSTRACT

Experimental Investigation of the Thermo-Mechanical and Chemical Behavior of Mixed Portland Cement–Calcium Sulfoaluminate Mortar Under Thermal Cycles

Amirhossein Moharrer[a*], Fattah Peiravian [b], Mohammad Jahani[c*]

[a] *Department of Civil Engineering Technical and Vocational University (TVU), Tehran, Iran; Concrete & Composite Unit Consultant, ShirazEskan Precast Concrete Technology Factory*
[b] *Ph.D. in Civil Engineering; Chairman of the Board, ShirazEskan Precast Concrete Technology Factory and ShirazEskan Company*
[c] *M.Sc. in Civil Engineering, University of Hormozgan; Concrete & Composite Senior Specialist, ShirazEskan Precast Concrete Technology Factory*

Keywords: Calcium Sulfoaluminate Cement, Mechanical Properties, Thermal Stress, Chemical Analysis, Rapid-Setting Mortar

1. Introduction

The development of rapid-setting cementitious materials is pivotal for modern construction, particularly in precast concrete technology. Calcium sulphoaluminate (CSA) cements have gained attention due to their accelerated hydration kinetics, enabling earlier initial and final setting compared to ordinary Portland cement (OPC). This study investigates the mechanical and chemical behavior of Portland-CSA blended mortars under thermal cycling, addressing the need for durable, high-performance materials in thermally fluctuating environments. CSA cements, characterized by high alumina (Al_2O_3) and sulphoaluminate phases, promote rapid strength development via the formation of ettringite (AFt) and stable hydrates. However, their long-term stability under thermal stress remains underexplored. This research evaluates two CSA types (IRC40, IRC50) blended with OPC, focusing on compressive strength evolution, thermal resistance, and phase composition. By analyzing performance before and after 24 thermal cycles (up to 110°C), the study aims to optimize CSA-OPC synergies for precast applications, balancing economic feasibility with enhanced durability.

2. Methodology

Mortar samples (5 cm^3 cubes) were prepared using OPC Type II, CSA cements IRC40 and IRC50, Ottawa sand, and potable water. Mix designs included 100% OPC, 100% CSA, and 10% CSA-90% OPC blends. Specimens were steam-cured at 60°C for 6 hours, water-cured, and subjected to thermal cycling (24 cycles: heating to 110°C, cooling to ambient). Compressive strength was tested at 1, 3, 7, and 28 days. Water absorption, specific gravity, and XRD analysis were conducted post-curing and post-thermal exposure. Chemical compositions of cements were analyzed via XRF (Table 2). Testing adhered to ASTM C109, C642, and C511.

3. Results and discussion

The enhanced mechanical and thermal performance of IRC50 cement is primarily due to its unique chemical composition and hydration behavior. Containing 49–53% Al_2O_3, IRC50 facilitates rapid ettringite (AFt) formation through reactions between calcium sulfoaluminate ($C_4A_3\check{S}$), water, and gypsum. This leads to a dense, interlocked microstructure that boosts early strength—IRC50 achieves 17 MPa at 1 day compared to OPC's 13.2 MPa. In contrast, OPC's strength depends on slower-forming C-S-H gels.

* Amirhossein Moharrer
E-mail addresses: amoharrer@nus.ac.ir (Amir Hossein Moharrer), Fattahp@gmail.com (Fattah Peiravian), Jahani.m.edu@gmail.com (Mohammad Jahani).

IRC50's lower CaO content (36–39% vs. OPC's 64.38%) reduces portlandite ($Ca(OH)_2$) formation. Since portlandite decomposes above 400°C, causing shrinkage and microcracking, its minimization improves thermal stability. IRC50 retains 45% more strength after thermal exposure (24.6 MPa vs. OPC's 16.9 MPa). Water absorption after thermal cycling increased by only 4.7% in IRC50, while OPC showed a 41% rise to 6.64%, indicating more severe microcracking in OPC.

XRD analysis confirmed the persistence of ettringite and low carbonation in IRC50 post-cycling, reflecting its structural integrity. These findings align with studies (e.g., Wang et al., 2024) highlighting CSA cement's thermal shock resistance due to phase-stable hydrates.

IRC40, while superior to OPC, exhibited intermediate performance due to lower Al_2O_3 (≥35%) and higher residual CaO, leading to less ettringite and more porosity under heat stress. Blended systems (10% CSA in OPC) showed a practical compromise—IRC50 blends retained 14.3% of early strength gain, versus 9% in IRC40 blends. Despite CSA's high cost (up to 10× OPC), even partial substitution improved hydration kinetics and thermal resilience. IRC50 blends also showed less post-thermal strength loss (9.3%) than IRC40 (7.4%), making them more suitable for thermally stressed precast applications.

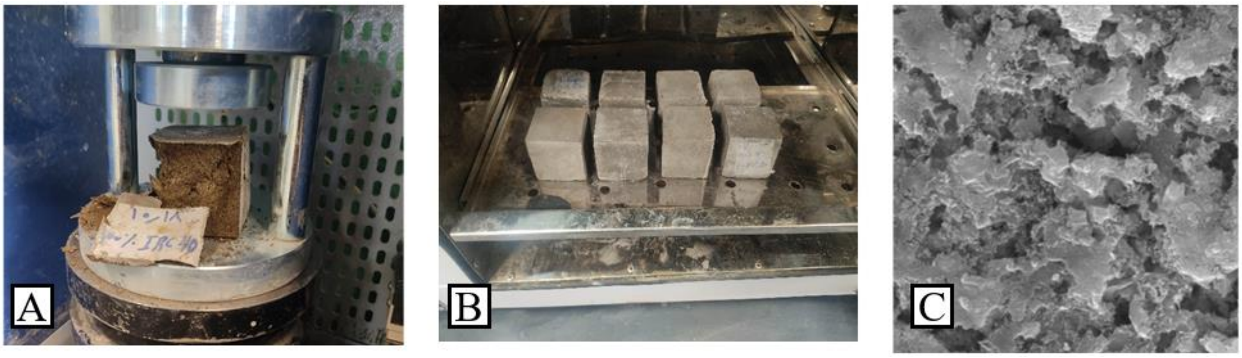

Fig. 1. (A) Compressive strength testing of mortar made with calcium sulfoaluminate cement; (B) Application of thermal cycles on samples made with a blend of calcium sulfoaluminate and Portland cements; (C) Microstructure of the cement paste made with calcium sulfoaluminate cement after exposure to thermal stress.

4. Conclusions

The findings of this study demonstrate that calcium sulphoaluminate (CSA) cements, particularly IRC50, exhibit superior early-age compressive strength and thermal stability compared to ordinary Portland cement (OPC), owing to their high alumina content ($Al_2O_3 \approx 50\%$) and rapid ettringite (AFt) formation during hydration. IRC50 achieved a 29% higher 1-day compressive strength (17 MPa vs. OPC's 13.2 MPa), attributed to the dense microstructure formed by interlocking ettringite crystals. The reduced CaO content in IRC50 minimized portlandite ($Ca(OH)_2$) formation, limiting thermal degradation and yielding 45% greater post-thermal strength retention (24.6 MPa vs. OPC's 16.9 MPa). Blending 10% IRC50 with OPC optimized cost-performance ratios, enhancing compressive strength by 14.3% and reducing water absorption by 4.7% after thermal cycling, making it viable for industrial applications .Chemical analyses via XRD confirmed that ettringite remained stable even after exposure to 110°C, underscoring its role in mechanical resilience. In contrast, OPC's reliance on C-S-H gels and portlandite increased vulnerability to thermal shock. However, challenges persist, including CSA's high production costs and the need for long-term studies on creep and shrinkage behavior .In summary, CSA-OPC blends offer a promising solution for precast concrete, enabling rapid formwork removal, energy efficiency, and durability in thermal environments. To advance industrial adoption, future research should focus on chemical additives (e.g., lithium carbonate) and lifecycle assessments (LCAs) to quantify environmental benefits, ensuring alignment with sustainable construction practices.

5. References

Jahani, M., Moradi, S., & Shahnoori, S, "4-year monitoring of degradation mechanisms of seawater sea-sand concrete exposed to tidal conditions: development of chemical composition and micro-performance", Construction and Building Materials, 2023, 409, 133475.

Guo, C., & Wang, R, "Influence of calcium sulfoaluminate cement on early-age properties and microstructure of Portland cement with hydroxypropyl methyl cellulose and superplasticizer" Journal of Building Engineering, 45, 103470.