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Research Article

Role of CTAC Surfactant in Enhancing the Physical and Microstructural Properties of Sustainable Cementitious Pastes

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Abstract

This study examines how the cationic surfactant cetyltrimethylammonium chloride (CTAC) affects the microstructural and physical characteristics of environmentally friendly, sustainable cementitious pastes. By systematically analyzing the density, air content, water absorption, thermal conductivity, and topography of hardened cementitious pastes, the study assesses the trade-offs between thermal insulation and structural integrity brought about by CTAC surfactant. The findings indicate that at 2% concentration, CTAC dramatically increases porosity (up to 49.4%) and reduces thermal conductivity ($0.24\ W{\bullet}m^{-1}{\bullet}K^{-1}$), but at the expense of compressive strength (79% compared with control). Changes in hydration disruption and pore structure lead to an increase in water absorption from 2.1 to 6.8%. According to the study, the best range for mechanical and insulating viability was between 0.5% and 1.0% CTAC. These results underscore the potential of CTAC in creating lightweight, thermally efficient building materials and also highlight the importance of tuning the concentration to achieve optimal performance and durability.

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Introduction

Efforts towards energy-efficient construction enhanced the interest in the insulating materials, especially for exterior walls, which constitute many building envelopes and critically influence thermal performance (Harvey, 2009; Haj Hussein et al., 2022). Ordinary construction units, such as standard bricks, often exhibit insufficient thermal insulation properties, encouraging researchers to explore advanced materials that are efficient in reducing energy consumption and environmental footprints (Zhou et al., 2012; Peng et al., 2008). Among these innovations, foam cementitious paste has become a promising solution due to its low density, desirable thermal conductivity, and structural versatility, allowing its dual functionality as a thermal insulator and load-bearing component (Bumanis, 2013). Additionally, its cost-effectiveness, ease of production, and sustainable attributes position it as a viable modern eco-friendly construction.

The efficacy of insulation materials depends on their capacity to diminish heat transfer between outdoor and indoor environments, thereby regulating internal temperatures and preventing condensation (Meletse, 2005). In foam cementitious systems, thermal conductivity is determined by microstructural parameters such as porosity, bulk density, moisture content, and chemical composition (Bremner et al., 2000). Notably, the air content within the cement matrix enhances insulation performance, as air has an inherently low thermal conductivity. Practical studies have further established an inverse correlation between thermal conductivity and porosity, with higher water-to-cement (w/c) ratios increasing porosity and thus improving insulation (Uysal, 2004; Bessenouci, 2011).

To improve mechanical and pore structure performance, surfactants as surface-active agents have been investigated for their ability to modify cementitious matrices. Surfactants are amphipathic compounds used to reduce a liquid's surface tension and interfacial tension between two phases. Surfactant molecules have two parts, a polar head (hydrophilic) and a nonpolar tail (hydrophobic). Surfactants are classified, based on the charge of the head group, into four categories: anionic, cationic, non-ionic, and amphoteric. CTAC is a cationic surfactant, which has a positive charge in its head. (Maglad et al., 2024; Zargar & Srivastava, 2024).

Surfactant chemical composition, concentration, the presence of other substances (such as salts or solvents), temperature, and pH were found to be the main factors that influence the surfactant behavior in the cement pastes. (Hu et al., 2025).

Surfactant molecules start to aggregate in aqueous solutions to form micelles in a concentration called critical micelle concentration (CMC). CMC affects the surfactant behavior in cement paste. It plays a key role in modifying the properties of cementitious materials and, as a result, enhances the hydration reactions, affecting the rate of CSH formation and strength progression. Micelles also help refine pore distribution and reduce surface tension, leading to improved consistency and homogeneity (Mabrouk et al., 2023; Chen et al., 2024; Samchenko et al., 2023).

Cetyltrimethylammonium Chloride (CTAC), a cationic surfactant, has attracted attention for its influence on the rate of hydration and the evolution of microstructure. Through the CTAC surfactant adsorption onto cement particles, CTAC affects particle dispersion, hydration product formation (e.g., calcium silicate hydrate (C-S-H) and calcium hydroxide ($Ca(OH)_2$)), and pore optimization (Snoeck et al., 2017; Zhang et al., 2019). However, the increment of CTAC concentrations may weaken mechanical strength by creating a non-uniform porosity,

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reinforcing the necessity of accurate dosage adjustment (Jones & McCarthy, 2005).

This study aims to rigorously evaluate the physical and microstructural effects of CTAC blending in sustainable and eco-friendly cementitious pastes. Key behavior parameters, including density, compressive strength, water absorption, thermal conductivity, and microstructure performance, will be analyzed to identify the optimal surfactant concentration that balances enhanced thermal insulation with structural durability and sustainability.

Materials

1. **Cement:** Ordinary Portland cement (OPC) of grade CEM I 52.5N, compliant with international standards, was sourced from El-Arish Cement Factory. The chemical composition of the cement, as determined by X-ray fluorescence (XRF) analysis, is provided in Table 1.

2. **Water:** Potable water from local sources is used. All mixing water used in this study complied with the requirements of ASTM C1602/C1602M.

3. **Surfactant:** Cetyltrimethylammonium chloride (CTAC), a cationic surfactant with the chemical formula $C_{19}H_{42}ClN$, was procured from Sigma-Aldrich. The key physicochemical properties of CTAC are summarized in Table 2.

Table 1. The chemical composition of the ordinary Portland cement (OPC).

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	Cl^-	MgO	SO_3	Free CaO	Ignition Loss
(%)	22.12	5.56	3.69	62.87	0.26	0.11	0.02	2.36	0.91	0.92	1.22

Table 2. Specification of Cetyltrimethylammonium chloride (CTAC) solution

Specification	
Chemical formula	$CH_3(CH2)_{15}N(Cl)(CH3)_3$
Molar mass	320.0 g/mol
Appearance	Clear colorless liquid
density	0.968 g/mL at 25 °C
Active matter	25 wt. % in H_2O
Character	cationic surfactant
pH at 25C0	6-8

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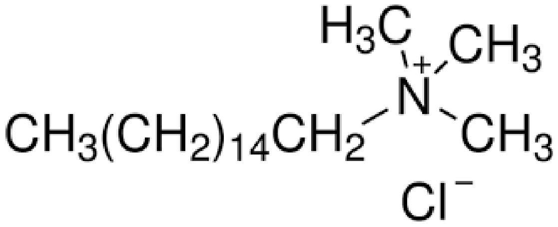

Figure 1: Chemical structure of cetyltrimethylammonium chloride (CTAC).

Methods

Paste Preparation

Cement paste samples were prepared by dissolving CTAC in potable water at concentrations ranging from 0.1% to 2% by weight of cement. A constant water-to-cement (w/c) ratio of 0.43 was maintained for all mixes. The surfactant-water solution was blended with CEM I 52.5N Portland cement using a mechanical mixer under continuous vigorous stirring (approximately 3 minutes) to ensure homogeneity. The resultant paste was cast into cubic molds (10 cm × 10 cm × 10 cm) and cured at 100% relative humidity and room temperature (23 ± 2°C) for 24 hours. After molding, the samples were immersed in water until testing at hydration ages of 3, 7, and 28 days, as recommended. The hydration periods of 3, 7, and 28 days were selected based on standard cement testing protocols (e.g., ASTM C109/C109M), representing early, intermediate, and long-term hydration phases. This timeframe allows for a comprehensive understanding of strength development and microstructural evolution.

Compressive Strength Testing

Compressive strength was evaluated using a CEMASCO Controls point-load testing machine (Model 20063, Milano, Italy). For each mix design, three replicates were tested at 3, 7, and 28 day hydration intervals. The mean value of the triplicate measurements were reported as the compressive strength. Loading was applied constantly according to ASTM C109/C109M guidelines.

Bulk Density and Air Content

Bulk density and air content were determined in accordance with ASTM C138-08. Samples were weighed in air (W_{air}) and submerged in water (W_{water}) to calculate density (ρ) using the formula:

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$$\rho = \frac{W_{\text{air}}}{W_{\text{air}} - W_{\text{water}}} \times \rho_{\text{water}}$$

where ρ_{water} = g/cm^3. The air content percent was derived from the theoretical density of air-free paste and the measured bulk density.

Thermal Conductivity Measurement

Thermal conductivity (k) was assessed via the steady-state guarded hot plate method (ASTM C177). Eight disc-shaped samples (130 mm diameter × 30 mm thickness), two per mix, were prepared. The thermal conductivity coefficient was calculated as:

$$k = \frac{q_x \cdot x}{\Delta T}$$

Where:

- k = Thermal conductivity (W·m^{-1}·K^{-1}),
- qx = Heat flux (W·m^{-2}),
- x = Sample thickness (m),
- ΔT = Temperature gradient across the sample (°C).

Water Absorption Test

Water absorption was quantified following ASTM C642. Samples were oven-dried at 105°C for 24 hours to determine the dry mass (M_0). After immersion in water for 24 hours, surface moisture was removed using a damp cloth, and the saturated mass (M_1) was recorded. Water absorption (WA) was calculated as:

$$WA\ (\%) = \frac{M_1 - M_0}{M_0} \times 100$$

Scanning Electron Microscopy (SEM) Analysis

The topography and microstructure of the dried hydrated samples are studied using JEOL JXA 840 electron probe microanalyzer SEM. The samples are coated with a thin film of gold under a vacuum evaporator with cathode rays and then analyzed.

Result and Discussion

Effect of CTAC Dose on Bulk Density and Air Content

The insertion of a cationic surfactant, Cetyltrimethylammonium Chloride (CTAC) in the cement paste affects the air content and bulk density of cement pastes, strongly affecting their mechanical and thermal properties. Air content, a key parameter affecting density, compressive strength, and thermal conductivity, is regulated by CTAC's surfactant concentration. During mixing, CTAC molecules adsorb at the air-water interface, minimizing surface tension and stabilizing entrapped air bubbles.

As shown in Table 3 and Figure 2, the air content of hydrated samples at 28 days increased progressively with CTAC concentration, peaking at 49.45% for the 2% CTAC mix (M4), compared to 0% in the control sample (M0). This rise in porosity is inversely proportional to bulk density, which decreased from 2.0 g•cm^{-3} (M0) to 1.01 g•cm^{-3} (M4). This inverse relationship between air content and density is in agreement with previous studies (Qaraman et al., 2017; Qaraman & Zuhud, 2018).

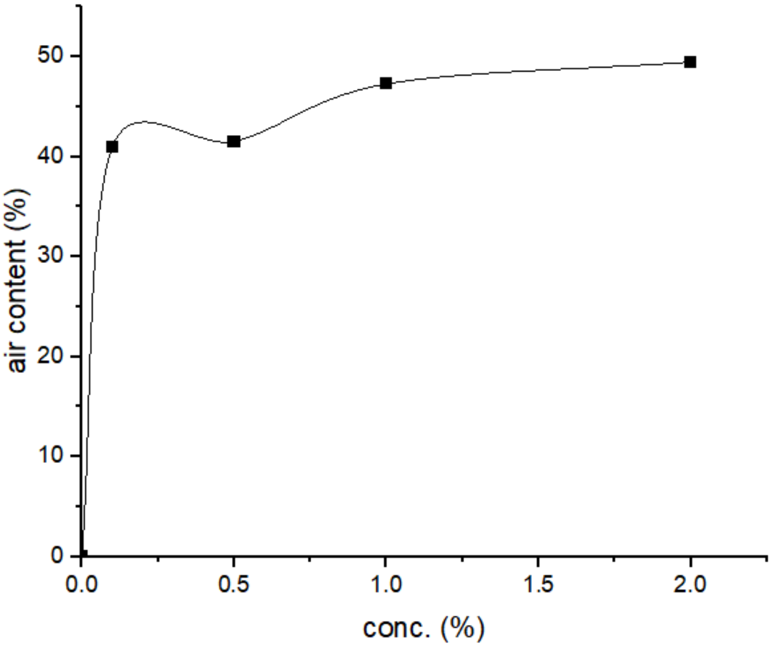

Figure 2. Relationship between CTAC concentration and air content in hardened cement paste at 28 days

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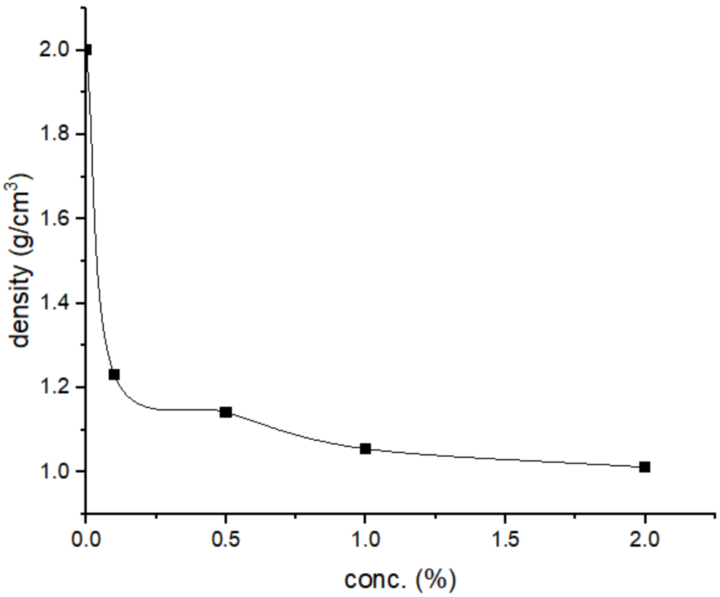

Figure 3. Relationship between bulk density and air content in CTAC-modified cementitious pastes at 28 days

Table 3. Composition and properties of foam cement paste mixes

Mixture	Cement/ water ratio	CTAC (%)	Density (gm/cm3)	Air %	Compressive Strength (N/mm^2)			Water Absorption %	Thermal conductivity $W•m^{-1}•K^{-1}$
					3 days	7 days	28 days		
M0	0.43	0.0	2.0	0.0	40.42	50.38	72.7	2.1	0.72
M1	0.43	0.1	1.181	40.95	16.04	20.03	28.90	4.5	0.30
M2	0.43	0.5	1.170	41.50	15.93	19.65	27.70	5.9	0.28
M3	0.43	1.0	1.055	47.25	8.66	10.81	15.60	6.6	0.25
M4	0.43	2.0	1.011	49.45	8.21	10.23	14.99	6.8	0.24

(The error margins are estimated as follows: density ± 0.01 g/cm^3, air content ± 0.5%, compressive strength ± 1.0 N/mm^2, water absorption ± 0.1%, and thermal conductivity ± 0.01 $W·m^{-1}·K^{-1}$.)

Analysis of Surface Topography and Microstructure

The scanning electron microscope (SEM) is a good tool to investigate the surface topography and microstructure of cementitious materials. Due to its high resolution and powerful depth of focus, it analyzes surface roughness and topography of cement paste hydration products, like calcium silicate hydrate (C-S-H) and calcium hydroxide (CH) and microscopic pores in hardened cement pastes.

Figure 4 shows the macroscopic surface topography of hardened cement paste samples at 28 days of hydration, highlighting the increase in porosity with increasing CTAC concentrations

(0% to 2%). It is noticeable that the control sample (0% CTAC) revealed a dense, non-porous structure, interconnected with its high bulk density (2.0 g·cm^{-3}) and compressive strength (72.7 N·mm^{-2}). In contrast, the 2% CTAC specimen showed the highest air content (49.45%) besides the lowest density (1.01 g/cm^{3}), in addition to a uniform distribution of small air voids, resulting in a significantly lower thermal conductivity (0.24 W•m^{-1}•K^{-1}). According to these results, the 2% CTAC concentration—which exhibited the most prominent structural and thermal changes—was selected for a closer microstructural examination using a scanning electron microscope (SEM), shown in Figure 5.

Figure 5 investigates the hydration products and pore structure of the 2% CTAC formulation at 7 and 28 days. At day 7 (Figure 5b), the CTAC-modified cement paste showed hexagonal CH plates and fibrous C-S-H gels embedded with spherical air voids (average size: 82.3 µm), as a characteristic result of the surfactant-induced stabilization. At day 28 (Figure 5d), the matrix showed a dense C-S-H network with retention of porosity, consistent with a progressive increase in strength (14.99 N•mm^{-2}). While the 2% CTAC dose enhanced thermal efficiency, the trade-off between mechanical strength and porosity highlights the importance of balancing surfactant concentration for structural viability in energy-efficient applications.

Scanning Electron Microscope (SEM) analysis demonstrated that CTAC-modified cement pastes developed a more uniform and finer pore structure, with average air voids around 82.3 µm. These pores, stabilized by surfactant micelles, promoted a denser calcium silicate hydrate (C–S–H) gel and enhanced hydration kinetics, despite increased total porosity. The regular distribution of air bubbles improved thermal insulation, though strength loss remains a concern. As confirmed by Jiang et al. (2023, a refined and well-connected pore structure is critical in determining mechanical integrity. Similarly, Vishavkarma and Venkatanarayanan (2024) emphasized that pore distribution homogeneity in foamed concretes significantly influences durability and thermal performance, underscoring the importance of optimized mix design.

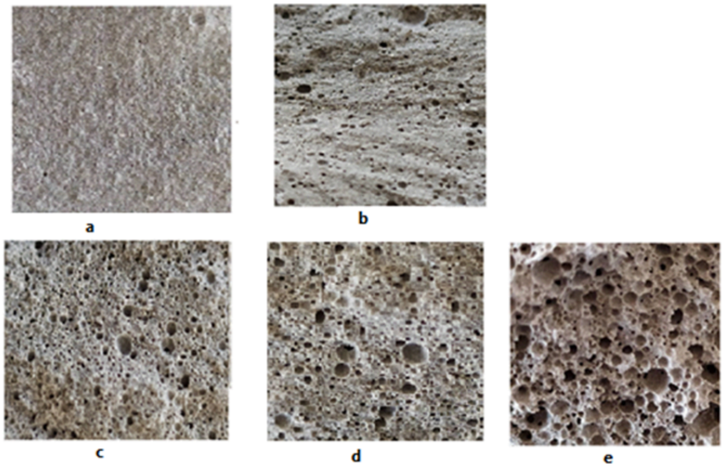

Figure 4. Macroscopic surface topography of hardened cement paste samples at 28 days of hydration (5× magnification):(a) Control sample (0% CTAC) with a dense, non-porous structure. (b) 0.1% CTAC: Initial formation of sparse air voids. (c) 0.5% CTAC: Moderate porosity with distributed air pockets.(d) 1%

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CTAC: Increased uniformity and density of air voids. (e) 2% CTAC: Highly porous matrix dominated by uniform, spherical air voids.

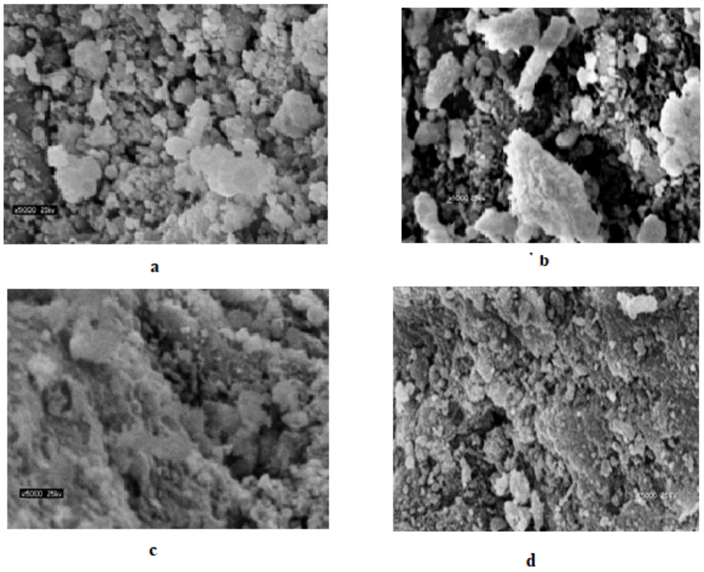

Figure 5. Scanning electron microscopy (SEM) images of hardened cement pastes at **5000× magnification**:

(a) Control sample (0% CTAC) and **(b)** 2% CTAC after **7 days** of hydration.
(c) Control sample (0% CTAC) and **(d)** 2% CTAC after **28 days** of hydration.

Effect of CTAC on the Compressive Strength of the Hardened Cement Paste

Compressive strength is equally as critical as density in evaluating the performance of cement pastes. Due to the time-dependent nature of cement hydration, compressive strength assessments should be performed at standardized hydration ages.

Due to the time-dependent nature of cement hydration, the compressive strength of hardened cement paste specimens—both with and without CTAC— was evaluated at different hydration ages. Measurements were taken at 3, 7, and 28 days of hydration using triplicate samples for each mix (M0-M4). The average values, shown in Table 3, indicated a steady increase in compressive strength values, which is attributed to the C-S-H growth resulting from the gradual hydration of cement.

Figure 6 shows that the compressive strength peaked at 28 days, with the control sample M0 (0% CTAC) reaching the maximum value (72.7 N^{-}mm^{-2}). It is also observed that the compressive strength is inversely proportional to the CTAC dosage, reaching the minimum value of 14.99 N•mm^{-2} for the 2% CTAC mixture (M4). This inverse relationship between CTAC concentration and compressive strength is due to the surfactant efficiency as an air-entraining agent. This high air content (40.95-49.45% in M1-M4) leads to high porosity, which affects the structural integrity. All cement pastes modified with CTAC maintained acceptable levels of compressive strength. This is attributed to the ability of CTAC to distribute voids in a regular and small manner, with an average void size of

82.3 micrometers as shown by SEM analysis, which maintained the cohesion of the matrix and reduced the stress level (Qaraman, 2016; Sun et al., 2024).

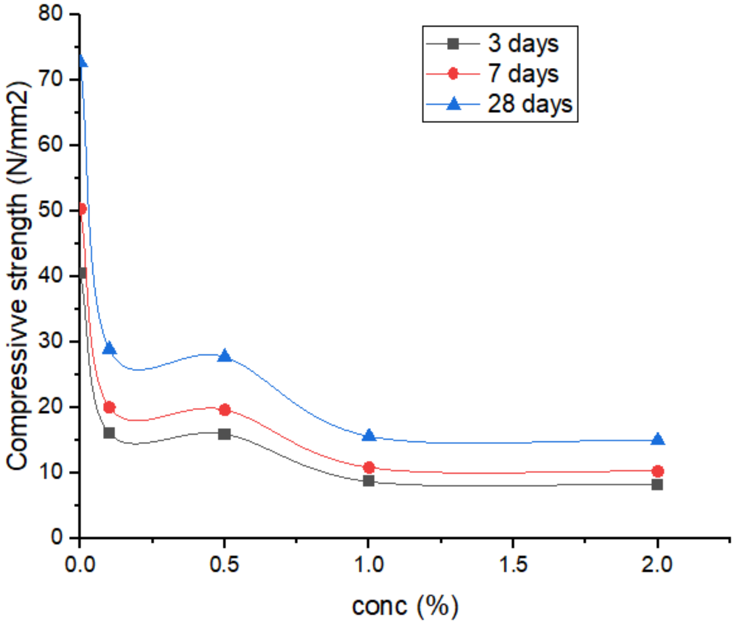

Figure 6. Compressive strength development of CTAC-modified cementitious pastes at **3, 7, and 28 days** of hydration

Effect of Density on Thermal Conductivity of Foam Cement Paste

Thermal conductivity, a critical parameter in assessing the insulation efficiency of lightweight cementitious materials, is intrinsically linked to the material's density and porosity. Foam cement paste derives its insulating capabilities from a cellular structure dominated by air-filled voids, which impede heat transfer. For instance, Chen et al. (2013) highlighted that a foam cement paste with a density of 400 $kg{\cdot}m^{-3}$ exhibits thermal insulation comparable to a 25 mm-thick cork layer, emphasizing its suitability for energy-efficient construction.

As demonstrated in Figure 7 and Table 3, thermal conductivity decreases proportionally with reduced density across all tested formulations. The control sample (0% CTAC), with a density of 2.0 $g{\cdot}cm^{-3}$, exhibited a thermal conductivity of 0.72 $W{\cdot}m^{-1}{\cdot}K^{-1}$, while the 2% CTAC-modified paste, with a density of 1.01 $g{\cdot}cm^{-3}$, achieved a significantly lower conductivity of 0.24 $W{\cdot}m^{-1}{\cdot}K^{-1}$. This inverse relationship stems from the increased air content (49.45%) and porosity in low-density pastes, where entrapped air voids act as thermal insulators by disrupting conductive pathways (Meletse, 2005; Bumanis, 2013).

The underlying mechanism involves the role of porosity in limiting phonon propagation—the primary mode of heat transfer in solid matrices. Higher porosity reduces the continuity of the cementitious framework, thereby diminishing thermal conduction. While CTAC-modified

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pastes (e.g., 2% CTAC) achieve exceptional thermal performance, the balance between insulation and mechanical integrity must be carefully calibrated for structural applications. These findings underscore foam cement paste's potential as a dual-function material, offering both thermal efficiency and lightweight properties when optimized with surfactants like CTAC.

The relationship between density and thermal conductivity in CTAC-modified foam cement paste was rigorously analyzed, revealing a strong inverse correlation, quantified by a linear regression coefficient of $R2=0.98$ (Figure 7). This statistical validation confirms that reducing density from 2.0 $g\cdot cm^{-3}$ (control) to 1.01 $g\cdot cm^{-3}$ (2% CTAC) directly lowers thermal conductivity from 0.72 $W\cdot m^{-1}\cdot K^{-1}$ to 0.24 $W\cdot m^{-1}\cdot K^{-1}$, aligning with the insulating mechanism of air-entrained porosity. While this performance surpasses traditional dense cementitious material, the CTAC-modified paste exhibits higher conductivity than specialized insulators like expanded polystyrene (EPS: 0.033–0.040 $W\cdot m^{-1}\cdot K^{-1}$) or mineral wool (0.030–0.045 $W\cdot m^{-1}\cdot K^{-1}$) (Jelle, 2011). However, its dual role as a structural and insulating material—retaining 14.99 $N\cdot mm^{-2}$ compressive strength—positions it uniquely for applications requiring multiple functions.

Practically, the 2% CTAC formulation could revolutionize sustainable construction in:

1. Building Envelopes: Replacing conventional blocks in moderate climates (e.g., Mediterranean regions) to reduce thermal bridging.
2. Prefabricated Panels: Streamlining assembly in low-rise structures while minimizing weight.
3. Retrofitting: Enhancing insulation in existing buildings without structural overhauls.

This balance of thermal and mechanical performance underscores CTAC's potential as a scalable, eco-friendly alternative, bridging the gap between insulation efficiency and structural viability.

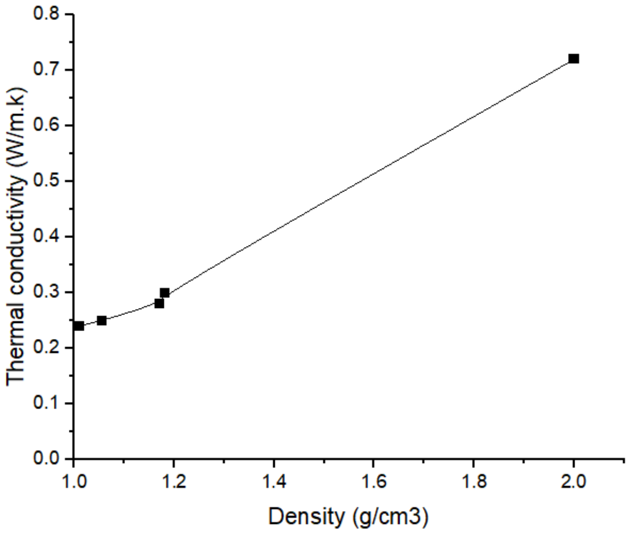

Figure 7. Inverse correlation between thermal conductivity and density in CTAC-modified cementitious pastes after 28 days of hydration

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Effect of CTAC on the Water Absorbance of the Hardened Cement Paste

Figure 8 and Table 3 reveal a clear dose-dependent relationship between CTAC concentration and water absorption in hardened cement paste, with values escalating from 2.1% (0% CTAC) to 6.8% (2% CTAC) after 28 days of hydration. This increase is attributed to CTAC's multifaceted impact on the cementitious matrix. Primarily, CTAC adsorption on cement particles modifies pore structure, creating a more interconnected network that enhances permeability (Jierula et al.,2024). Concurrently, CTAC interferes with hydration kinetics, disrupting the formation of calcium silicate hydrate (C-S-H) and yielding a porous, less dense microstructure (Snoeck et al., 2017). At higher concentrations, surfactant saturation within pores further inhibits hydration, amplifying porosity (Gholizadeh-Vayghan et al., 2020). Additionally, CTAC's amphiphile nature alters the water-cement interface, reducing surface tension and promoting uneven water distribution, which exacerbates structural inhomogeneity (Bentz & Ferraris, 2010). Despite this rise in water absorption, the observed range (2.1–6.8%) remains within acceptable limits for foam cement pastes, which typically exhibit 5–15% absorption due to their inherently porous nature (Cong et al.,2024). To mitigate durability risks—such as freeze-thaw degradation or chemical ingress—while retaining thermal benefits, optimizing CTAC dosage (e.g., 0.1–0.5%) is critical. This balance ensures minimal water uptake without sacrificing insulation efficiency, underscoring the necessity of tailoring surfactant chemistry to harmonize functional performance with long-term resilience in energy-efficient construction materials.

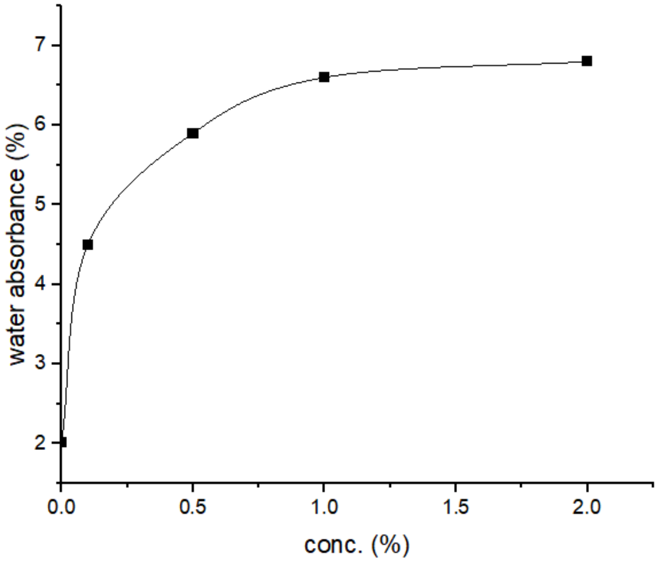

Figure 8. Dose-dependent increase in water absorption of CTAC-modified cementitious pastes after 28 days of hydration.

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Conclusion

The blending of CTAC as an air-entraining agent in cementitious pastes demonstrates a transformative capacity to enhance thermal insulation and reduce density through controlled porosity. However, this comes with inherent trade-offs: higher CTAC concentrations (>1%) drastically reduce compressive strength and increase water absorption, posing durability risks. SEM analysis corroborates that CTAC modifies pore architecture, stabilizes air voids, and disrupts hydration kinetics, yielding a lightweight yet mechanically compromised matrix. The optimal CTAC dosage (0.5–1%) achieves a balance, offering 0.25–0.28 $W \cdot m^{-1} \cdot K^{-1}$ thermal conductivity while retaining 15–28 $N \cdot mm^{-2}$ compressive strength—suitable for non-load-bearing insulation applications. Comparatively, although CTAC-modified materials are not as insulating as specialized materials (e.g., polystyrene) they offer structural-insulation duality. Future work should focus on long-term durability assessments, environmental resistance (e.g., freeze-thaw, sulfate attack), and exploring hybrid surfactant systems to further optimize performance. This research advances the development of sustainable, energy-efficient cementitious composites, emphasizing the critical role of surfactant chemistry in multifunctional material design.

Limitations of the study

This study presents promising findings regarding the use of CTAC-modified cement pastes; however, several limitations must be acknowledged. First, the experiments were conducted under controlled laboratory conditions, which may not fully replicate real-world environmental stresses and variability in field applications. Second, the study did not include long-term durability evaluations such as freeze-thaw resistance, sulfate attack, or carbonation—factors critical to the practical viability of the modified materials. Third, only a single cationic surfactant (CTAC) was investigated; broader comparisons involving different surfactant types (anionic, non-ionic, or amphoteric) could yield a more comprehensive understanding of micelle effects on cementitious systems. Fourth, the results were obtained using Ordinary Portland Cement (OPC) of grade CEM I 52.5N; therefore, they may not be directly applicable to other cement types. Variations in mineral composition and reactivity of different cement types (e.g., pozzolanic or sulfate-resistant cements) may alter the interaction with surfactants, affecting hydration behavior, pore structure, and mechanical performance. Caution is thus advised when generalizing the findings beyond OPC systems.

Supplementary Materials and Data Availability Statement: Not applicable. All data are included in the main text of the manuscript.

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References

ASTM International. (2008). Standard test method for density (unit weight), yield, and air content (gravimetric) of concrete (ASTM C138/C138M-08).

ASTM International. (2019). Standard test method for steady-state heat flux measurements and thermal transmission properties by means of the guarded-hot-plate apparatus (ASTM C177-19).

ASTM International. (2021). Standard test method for compressive strength of hydraulic cement mortars (using 2-in. or [50-mm] cube samples) (ASTM C109/C109M-21).

ASTM International. (2021). Standard test method for density, absorption, and voids in hardened concrete (ASTM C642-21).

Bentz, D. P., & Ferraris, C. F. (2010). Rheology and setting of high-volume fly ash mixtures. Cement and Concrete Composites, 32(4), 265–270. https://doi.org/10.1016/j.cemconcomp.2010.03.001

Bessenouci, H. (2011). The impact of porosity on the thermal properties of building materials. Journal of Materials Science, 46(15), 5105–5114. https://doi.org/10.1007/s10853-011-5574-9

Bremner, T. W., Malhotra, V. M., & Bilodeau, A. (2000). Thermal conductivity of cementitious materials. Cement and Concrete Research, 30(4), 649–654. https://doi.org/10.1016/S0008-8846(00)00225-3

Bumanis, G. (2013). Lightweight concrete with improved thermal insulation properties. Journal of Civil Engineering and Management, 19(5), 619–626. https://doi.org/10.3846/13923730.2013.799093

Chen, J., Hou, L., Nan, J., Ni, B., Dai, W., & Ge, X. (2024). Prediction of critical micelle concentration (CMC) of surfactants based on structural differentiation using machine learning. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 703, 135276. https://doi.org/10.1016/j.colsurfa.2024.135276

Cong, X., Tang, Z., Zang, T., Lu, S., Tan, Y., Wang, Z., & Huang, T. (2024). Investigation of the pore structures and water absorbency of foamed alkali-activated binders. Journal of Materials in Civil Engineering, 36(3), 04023609. https://doi.org/10.1061/(ASCE)MT.1943-5533.0004922

Gholizadeh-Vayghan, A., Masoumi, S., & Shekarchi, M. (2020). Effect of surfactants on the hydration and durability of cementitious materials. Construction and Building Materials, 247, 118496.

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https://doi.org/10.1016/j.conbuildmat.2020.118496

Haj Hussein, M., Monna, S., Abdallah, R., Juaidi, A., & Albatayneh, A. (2022). Improving the thermal performance of building envelopes: An approach to enhancing the building energy efficiency code. Sustainability, 14(23), 16264. https://doi.org/10.3390/su142316264.

Harvey, L. D. D. (2009). Reducing energy use in buildings: How much, and at what cost? Science and Public Policy, 36(1), 19–28. https://doi.org/10.3152/030234209X415573

Hu, X., Dong, H., Zhou, Y., Shao, W., Liu, J., Sun, G., ... & Wu, M. (2025). Study on the influence of different surfactants on cement particles. Langmuir, 41(13), 8524–8534.

Jelle, B. P. (2011). Traditional, state-of-the-art and future thermal building insulation materials and solutions – Properties, requirements and possibilities. Energy and Buildings, 43(10), 2549–2563. https://doi.org/10.1016/j.enbuild.2011.05.015

Jiang, Z., Pan, Y., Fu, C., Li, W., Wang, Y., & Long, W. J. (2023). Three-dimensional pore structure characterization of cement paste by X-ray computed tomography (XCT) and focused ion beam/scanning electron microscopy (FIB/SEM). Construction and Building Materials, 383, 131379. https://doi.org/10.1016/j.conbuildmat.2023.131379

Jierula, A., Li, H., Chen, Y., Wu, C., Wu, X., & Yin, H. (2024). Study on the influence of density and water–cement ratio on the cement utilization, fluidity, mechanical properties, and water absorption of foam concrete. Buildings, 14(11), 3550.

Jones, M. R., & McCarthy, A. (2005). Behavior of foam concrete in structural applications. Materials and Structures, 38(4), 289–300. https://doi.org/10.1007/BF02479293

Mabrouk, M. M., Hamed, N. A., & Mansour, F. R. (2023). Spectroscopic methods for determination of critical micelle concentrations of surfactants: A comprehensive review. Applied Spectroscopy Reviews, 58(3), 206–234. https://doi.org/10.1080/05704928.2022.2080210

Maglad, A. M., Mydin, M. A. O., Datta, S. D., Abbood, I. S., & Tayeh, B. A. (2024). Impact of anionic surfactant-based foaming agents on the properties of lightweight foamed concrete. Construction and Building Materials, 438, 137119. https://doi.org/10.1016/j.conbuildmat.2024.137119

Meletse, M. (2005). Thermal insulation principles and applications. Building Science Journal, 18(3), 45–52.

Peng, H., Jiang, Y., & Hu, Y. (2008). Energy-saving potential of a ventilated cavity structure applied to building envelopes. Energy and Buildings, 40(9), 1645–1655. https://doi.org/10.1016/j.enbuild.2008.02.016

Priyatham, B. P. R. V. S., Lakshmayya, M. T. S., & Chaitanya, D. V. S. R. K. (2023). Review on performance and sustainability of foam concrete. Materials Today: Proceedings.

Qaraman, A. F. A. (2016). The efficiency of mixed surfactants as air entraining agents in cement pastes. European Journal of Material Sciences, 3(3), 12–22.

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Qaraman, A. F. A., & Zuhud, A. (2018). The influence of using Cocamidopropyl Betaine as chemical additive on thermal and physical properties of foam mortar. Asian Journal of Natural & Applied Sciences, 7(3), 12–21.

Qaraman, A. F. A., Musalam, A. M., & El-Hassayna, I. M. (2017). The behavior of Lauryl Glucoside as cement paste admixture. Israa University Journal for Applied Science, 1(1), 7–15.

Samchenko, S. V., Kozlova, I. V., Zemskova, O. V., & Dudareva, M. O. (2023). Exploring the surface chemistry for the stabilization of Bismuth Titanate fine particle suspensions in cement systems. Nanotekhnologii v Stroitel'stve, 15(5), 397–407.

Snoeck, D., Pel, L., & De Belie, N. (2017). The influence of surfactants on cement hydration and microstructure. Cement and Concrete Research, 98, 34–44. https://doi.org/10.1016/j.cemconres.2017.03.012

Sun, X., Zhong, J., Zhang, W., Li, G., Cao, H., & Gao, P. (2024). Deformation and mechanical properties of foamed concrete under various components and pore structure. Journal of Building Engineering, 94, 109920. https://doi.org/10.1016/j.jobe.2024.109920

Uysal, H. (2004). Effect of w/c ratio on the properties of cementitious materials. Cement and Concrete Composites, 26(6), 773–778. https://doi.org/10.1016/j.cemconcomp.2004.01.003

Vishavkarma, A., & Venkatanarayanan, H. K. (2024). Assessment of pore structure of foam concrete containing slag for improved durability performance in reinforced concrete applications. Journal of Building Engineering, 86, 108939. https://doi.org/10.1016/j.jobe.2024.108939

Zargar, A. N., & Srivastava, P. (2024). Biosurfactants: Sustainable alternatives to chemical surfactants. In Industrial Applications of Biosurfactants and Microorganisms (pp. 425–436). Academic Press.

Zhang, X., Li, Q., & Ma, H. (2019). Effect of cationic surfactants on the hydration and durability of cement-based materials. Construction and Building Materials, 215, 440–450. https://doi.org/10.1016/j.conbuildmat.2019.04.158

Zhou, Y., Zhang, L., & Zhang, B. (2012). Influence of lightweight aggregate on the thermal properties of building materials. Construction and Building Materials, 30, 763–768. https://doi.org/10.1016/j.conbuildmat.2011.12.050

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