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ENHANCING CONCRETE PERFORMANCE WITH SILICON CARBIDE: INNOVATIONS AND FUTURE

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Abstract

Silicon carbide (SiC), a compound of silicon and carbon, is receiving increased attention in the construction sector due to its exceptional mechanical, thermal, and electromagnetic properties. This literature review examines the integration of SiC into concrete and other construction materials, with a focus on its potential to enhance performance, sustainability, and durability. The review highlights SiC's remarkable hardness and chemical stability, which contribute to improved structural integrity, increased resistance to wear and weathering, and enhanced crack mitigation. These characteristics make SiC particularly suitable for infrastructure subjected to extreme stresses, such as bridges, tunnels, and industrial flooring. Its high thermal conductivity supports energy-efficient applications, including heated pavements and advanced insulation systems, thereby reducing energy consumption and improving climate control in buildings. Additionally, SiC's electromagnetic shielding capabilities offer promising potential for smart infrastructure and intelligent transportation systems by mitigating electromagnetic interference. Despite its advantages, the widespread adoption of SiC faces challenges related to cost, scalability, and material optimization. The review underscores the need for continued research to refine SiC formulations, evaluate long-term environmental impacts, and explore novel applications in large-scale construction projects. Overall, SiC emerges as a transformative additive for modern concrete technologies, offering a pathway toward more resilient, energy-efficient, and sustainable infrastructure.

Keywords: silicon carbide, concrete durability, sustainable infrastructure, thermal conductivity, electromagnetic shielding.

1. Introduction

Concrete is one of the most widely used construction materials globally, forming the backbone of modern infrastructure. However, the production of Portland cement, the key binding component in concrete, generates significant greenhouse gas emissions, contributing to environmental degradation and climate change. In response, the construction industry is shifting toward more sustainable, durable, and high-performance alternatives, with growing interest in the incorporation of nanomaterials and industrial by-products. Among these, silicon carbide (SiC) has recently gained attention as a promising additive or partial replacement in cementitious composites.

Silicon carbide is a compound composed of silicon and carbon, renowned for its exceptional mechanical, thermal, and chemical properties. With a Mohs hardness of 9.5, it ranks just below diamond, offering superior resistance to wear and abrasion [1]. Its high thermal conductivity and melting point make it particularly suitable for applications in extreme environments, facilitating efficient heat dissipation and enhancing fire *resistance* in concrete elements. Additionally, SiC exhibits electrical conductivity, enabling the development of smart and functional materials such as electrically conductive concrete for snow-melting pavements and electromagnetic shielding structures.

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While silicon carbide has long been utilized in ceramic, electronic, and abrasive applications, its integration into cement-based systems remains relatively new. Current research highlights its potential to improve the mechanical strength, durability, freeze-thaw resistance, and chemical resilience of concrete. Moreover, industrial by-products and waste forms of SiC, including fine powders and residual sludge from manufacturing processes, can be repurposed in construction materials, supporting circular economy principles.

The sustainability appeal of SiC lies not only in performance enhancement but also in its potential to partially replace cement or fine aggregates, thereby contributing to reduced carbon emissions in concrete production. As emphasized by Ibrahim et al. [2], the disposal of industrial by-products in landfills presents both environmental and economic challenges. Utilizing materials such as SiC waste in structural and non-structural applications could simultaneously mitigate waste disposal issues and reduce the environmental footprint of construction projects.

This study presents a comprehensive review and synthesis of recent research on the incorporation of silicon carbide (SiC) into concrete and cementitious composites, focusing on its effects on mechanical and functional properties, environmental durability, and its potential contributions to sustainable construction practices.

2. Methodology

This review employed a systematic methodology to examine the application of silicon carbide (SiC) in cementitious materials, focusing on studies published between 2000 and 2025. Relevant literature was sourced from Scopus, Web of Science, ScienceDirect, and IEEE Xplore using targeted keywords such as "silicon carbide concrete," "SiC cement replacement," and "SiC additive in mortar." Inclusion criteria were limited to peer-reviewed journal articles, conference papers, and technical reports featuring experimental or modeling data involving SiC in powder, nano, or industrial waste forms. Excluded materials included patents, theses, articles without full-text access, and studies involving SiC in non-cementitious systems such as polymers or ceramics. The selected studies were categorized based on SiC's role as a cement replacement, sand replacement, or performance-enhancing additive. Evaluation parameters included compressive and flexural strength, microstructural analysis (e.g., SEM), and thermal behavior (e.g., TGA). Each study was assessed for methodological clarity, the use of control specimens, definition of mix proportions, and reproducibility. This methodology ensured that only relevant and rigorously conducted studies were analyzed to inform the synthesis of SiC's effects on concrete performance.

3. Properties of silicon carbide for cementitious applications

Abderrazak et al. [1] conducted a study to characterize the fundamental properties of silicon carbide (SiC), identifying its exceptional hardness (Mohs hardness ≈ 9.5) and high specific gravity (≈ 3.2), with applications across various particle sizes. For use in concrete, SiC is typically incorporated in powder or nano-scale form. Several studies have indicated that particle sizes around 80 nm yield the most significant enhancements in hardness and thermal conductivity. Chemically, SiC is regarded as stable and inert under standard conditions, exhibiting no adverse reactions with cementitious matrices—an attribute that makes it a viable long-term additive or filler. This chemical stability also contributes to SiC's high resistance to aggressive chemical environments, thereby enhancing the durability of concrete composites. Additionally, SiC maintains thermal stability up to 2700 °C. Abderrazak et al. [1] further highlight mechanical alloying as an effective synthesis technique for nanostructured SiC, whose combination of structural robustness, thermal endurance, and electrical functionality presents advantages for advanced applications in energy systems, electronics, and construction materials. Yinfei et al. [3] similarly emphasize SiC's high thermal conductivity and semiconductive behavior, noting its potential utility in smart concrete and thermally active flooring systems. Compared to traditional fillers, SiC offers multifunctionality, making it suitable for both structural and smart infrastructure applications.

Gao et al. [4] conducted a study to investigate the electromagnetic wave absorption characteristics of concrete incorporating silicon carbide (SiC). In addition to the primary objective, the authors reported several noteworthy findings regarding the influence of SiC on the microstructural and mechanical behavior of cementitious composites. The incorporation of SiC was found to enhance the densification of the cement matrix by hindering crack propagation and reducing localized stress concentrations through improved particle filling and bonding mechanisms. The study further concluded that a 10% replacement of cement with irregularly shaped SiC particles facilitated full contact and strong interfacial bonding between the particles and the cement paste. However, increasing the SiC content to 20% led to excessive particle interfaces and agglomeration, ultimately diminishing mechanical performance due to insufficient bonding. Additionally, the authors observed that SiC particles absorbed free water during the early stages of hydration, effectively lowering the actual water-to-cement ratio and contributing to improved strength development. These findings suggest that SiC not only imparts electromagnetic functionality but also significantly affects hydration dynamics and mechanical performance, although dosage sensitivity remains a limiting factor.

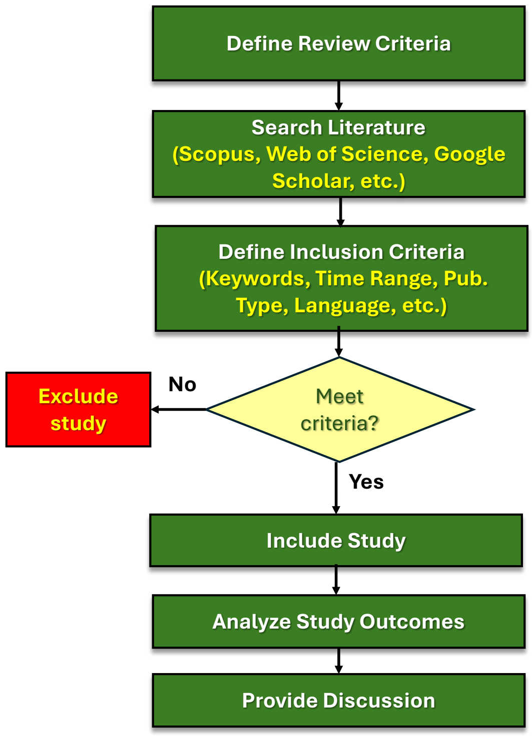

Fig. 1. Literature Review Flow Chart

Du et al. [5] conducted a study to investigate the influence of silicon carbide (SiC) particle fineness on the thermal and mechanical performance of cement-based composites. The research employed SiC particles of varying sizes at a fixed dosage to evaluate their effects on heat conduction, compressive strength, and microstructural development. The results demonstrated that finer SiC particles facilitated a more homogeneous dispersion within the cement matrix, thereby enhancing thermal conductivity and improving the interfacial bonding between the SiC particles and the surrounding cement paste. Consequently, composites incorporating finer SiC particles exhibited higher compressive strength and more efficient thermal transfer capabilities. The observed increase in thermal conductivity with decreasing particle size was attributed to reduced interfacial thermal resistance and improved particle contact. Similarly, the mechanical performance benefited from improved particle packing density and lower porosity. Scanning electron microscopy (SEM) analysis further confirmed that finer SiC particles promoted a denser microstructure with fewer voids and superior dispersion characteristics. Relative to coarser particles, fine SiC offers more effective integration into the cement matrix, thereby maximizing both thermal transfer and mechanical performance. In contrast to Gao et al. [4], who focused on dosage optimization, Du et al. [5] emphasize the critical role of particle size in achieving performance gains.

4. Performance of silicon carbide as a cement replacement

As a relatively recent addition to construction materials research, only a limited number of studies have investigated the incorporation of silicon carbide (SiC) as a replacement for ordinary Portland cement (OPC) in concrete mixtures. A study conducted by Jiang et al. [6] examined the feasibility of using industrial silicon carbide (SiC) waste as a supplementary material in cement mortar, promoting a sustainable and cost-effective recycling pathway. The SiC waste, composed mainly of SiC particles with minor impurities, was introduced into cement mortars in varying proportions as a partial replacement for cement. The experimental analysis included tests for workability, compressive strength, water absorption, and microstructural behavior. Results showed that the inclusion of SiC waste reduced mortar workability due to its irregular particle morphology and high surface area. However, compressive strength improved significantly at moderate replacement levels. Water absorption decreased with increasing SiC content, indicating improved matrix density and reduced pore connectivity. SEM analysis revealed a more refined microstructure with uniform dispersion of SiC particles, contributing to enhanced mechanical performance and durability. The research emphasizes the potential of SiC waste as an environmentally responsible material in the construction industry.

Overall, this study supports the recycling of SiC industrial byproducts in cementitious materials, offering both ecological benefits and mechanical performance enhancements when used within appropriate content limits.

5. Silicon carbide as fine aggregate replacement

Since SiC is considered a semiconductor, replacing aggregate with it facilitates the formation of conductive pathways within concrete, thereby increasing electrical conductivity. However, its irregular shape and poor gradation reduce workability and slump. Overall, replacing fine aggregates with silicon carbide enhances abrasion and wear resistance, making it suitable for heavy-duty and industrial applications. This tradeoff highlights the importance of optimizing SiC gradation for functional and practical performance.

Tadesse et al. [7] investigated the long-term effects of electric stress on cement mortar modified with silicon carbide (SiC), focusing on electrical durability and microstructural evolution. Mortar specimens with varying SiC contents were exposed to continuous electrical loading, with measurements taken for electrical resistance, internal temperature, and ion transport. Optical microscopy and SEM were used to assess physical integrity and microstructural changes. Results showed that SiC not only enhanced initial conductivity but also improved long-term stability under electrical stress. Higher SiC content delayed degradation mechanisms such as microcracking and pore coarsening, while its thermal buffering capacity suppressed internal temperature spikes. However, under excessive electric loading, localized heating and ionic migration were observed, especially in mixes with lower SiC ratios. The study concluded that SiC-modified mortars offer strong potential for applications such as electric heating, electromagnetic interference shielding, and self-sensing systems, provided that material composition and exposure conditions are carefully optimized to preserve both functional and structural performance. These findings underscore the importance of dosage control for durability in smart infrastructure and highlight SiC's dual role in electrical performance and thermal stability.

Park et al. [8] explored the enhancement of thermoelectric properties in cement composites through the partial substitution of fine aggregate with silicon carbide (SiC). The authors aimed to develop multifunctional concrete materials capable of energy conversion by investigating the Seebeck coefficient, electrical conductivity, and power factor. Experimental cement mixtures were prepared using different SiC replacement ratios. The results revealed that incorporating SiC increased both the electrical conductivity and Seebeck coefficient of the composites. As a result, the thermoelectric power factor improved significantly, particularly at 10–15% SiC replacement levels. Microstructure analysis showed that SiC particles contributed to conductive pathways within the cement matrix, promoting efficient charge transport. Meanwhile, compressive strength remained within structurally acceptable ranges, confirming that functional enhancements did not compromise the material's integrity. This study emphasizes the feasibility of using SiC to produce thermoelectric cement composites that combine energy conversion with mechanical viability, particularly in building applications involving waste heat recovery.

Woo et al. [9] investigated the thermal and mechanical behavior of cement composites incorporating silicon carbide (SiC) as a partial replacement for natural fine aggregates, focusing on improving ice-melting functionality for cold-region infrastructure. SiC was added at replacement levels of 0%, 25%, 50%, 75%, and 100% by volume. The resulting composites were tested for thermal conductivity, infrared-induced temperature rise, compressive strength, and deicing performance. The results showed that increasing SiC content significantly enhanced both thermal conductivity and infrared absorption, accelerating surface temperature rise and improving ice-melting capacity. At 100% SiC replacement, surface temperature increased by up to 80% over control samples, and the melted ice volume was approximately 3.5 times higher. Importantly, all mixes retained compressive strengths above 25 MPa, confirming their structural suitability for pavement use. This study demonstrates SiC's value as a passive functional additive, capable of enhancing thermal responsiveness in pavements without compromising mechanical integrity—making it especially promising for sustainable snow and ice mitigation strategies in civilian and military settings.

Shi et al. [10] examined the use of silicon carbide (SiC) as a partial fine aggregate replacement in concrete to enhance the thermal conductivity of geothermal energy piles. These foundation elements serve dual roles as structural supports and ground heat exchangers in sustainable building systems. However, conventional concrete limits heat transfer due to its inherently low thermal conductivity. To address this, the study replaced natural sand with SiC at volume fractions of 0%, 25%, 50%, 75%, and 100%, and evaluated thermal conductivity, compressive strength, and specific heat. A finite element model was also developed to simulate energy pile performance under geothermal loading. The results showed that SiC significantly increased thermal conductivity, with the 100% replacement mix exhibiting over 70% higher conductivity than the control. This enhancement translated into improved heat extraction and storage, as validated by thermal response tests and modeling. Although compressive strength slightly declined with higher SiC content, all mixes maintained values above 25 MPa, satisfying structural performance criteria. The SiC-modified concrete also demonstrated stable thermal behavior under repeated heating and cooling cycles. These findings highlight SiC's potential to enhance energy efficiency in geothermal systems, supporting its role as a functional filler in energy-responsive infrastructure without compromising essential mechanical thresholds.

Li et al. [11] investigated the mechanical and thermal performance of thermally conductive high-strength concrete (TCHSC) incorporating silicon carbide and graphite as partial replacements for fine aggregates. The aim was to enhance thermal conductivity without compromising structural integrity. Concrete specimens were evaluated at 7, 28, and 56 days for compressive, flexural, and splitting tensile strength, along with thermal conductivity. Results showed that the inclusion of conductive fillers increased thermal conductivity by up to 80% compared to control mixes, while maintaining compressive strength above 60 MPa. The optimal blend, featuring a balanced ratio of SiC and graphite, provided both high strength and improved heat transfer capability. Although flexural and tensile strengths declined moderately with increasing filler content, all values remained within acceptable engineering limits for high-strength concrete. SEM analysis confirmed uniform dispersion and a dense microstructure with low porosity, contributing to consistent thermal and mechanical performance. This study underscores the viability of using multifunctional fillers like SiC in TCHSC to meet dual performance demands, offering a practical solution for infrastructure requiring both load-bearing capacity and thermal responsiveness.

Yoo et al. [12] introduced a novel composite aggregate that combines phase change materials (PCMs) with silicon carbide (SiC) to improve the thermal resistance and post-fire mechanical performance of cementitious materials exposed to high temperatures. The PCM/SiC aggregate was fabricated through a two-step process: impregnation of PCMs into porous lightweight aggregates, followed by SiC coating. This design enabled dual functionality—latent heat absorption from PCMs and high thermal conductivity from SiC. The study evaluated four mortar types: natural, PCM-only, SiC-only, and PCM/SiC composite aggregates, subjecting them to temperatures up to 800 °C. Mortars containing PCM/SiC aggregates retained over 60% of their original compressive strength post-exposure, outperforming other mixes. Thermogravimetric analysis and SEM confirmed that the composite aggregates reduced internal temperature rise, delayed crack propagation, and preserved matrix cohesion. These findings highlight how the combination of PCMs and SiC improves both heat resistance and structural integrity, making them promising additives for fire-resistant concrete used in tunnels, high-rise buildings, and military facilities.

6. Silicon carbide as an additive

Filazi et al. [13] investigated the role of silicon carbide (SiC) as a functional additive in cementitious composites, focusing on mechanical strength, electrical conductivity, and durability. SiC was added in increments ranging from 1% to 16% by cement weight, with all other mix parameters held constant. Mechanical (compressive and flexural), durability (capillary absorption, chloride permeability), and microstructural properties (SEM/EDX) were evaluated. Increased SiC content reduced spread diameter, indicating reduced workability. Strength improved up to 8% SiC, with limited benefits beyond that. Durability improved notably at 8–12% SiC, and electrical conductivity increased across all dosages. SEM results showed dense, uniformly dispersed microstructures. This study identifies 8–12% SiC as the optimal range for enhancing both durability and functional performance, although workability concerns may require mitigation in practical applications.

Idrees et al. [14] examined the effects of silicon carbide (SiC), both independently and in combination with tungsten carbide (WC), on the mechanical and microstructural performance of cementitious composites. SiC was tested at dosages ranging from 1% to 4% by weight of cement. Tests included compressive and flexural strength, rapid chloride permeability (RCPT), and SEM imaging. The inclusion of SiC alone improved compressive strength by approximately 6% and flexural strength by 39% relative to the control (see Fig. 2, adapted from [14]), due to better particle packing and interfacial bonding resulting from SiC's angular morphology. Although performance improved with increasing SiC content, the optimal dosage was not reached, suggesting potential for further gains. However, RCPT results showed higher chloride permeability at 4% SiC, raising concerns about long-term durability in corrosive environments. The study supports SiC's value as a mechanical enhancer in concrete but also highlights a tradeoff between strength and durability. Dosage optimization is necessary to balance performance with resistance to ionic ingress.

Kim et al. [15] evaluated the thermal energy storage performance of a novel composite aggregate consisting of phase change materials (PCMs) encapsulated in silicon carbide (SiC) shells. The study aimed to develop multifunctional concrete capable of storing and releasing heat while maintaining structural performance. Specimens were tested for thermal conductivity, latent heat storage, and phase stability using differential scanning calorimetry (DSC) and monitored under simulated thermal conditions. Results showed that the PCM/SiC aggregate enabled repeated energy storage cycles without compromising compressive strength. SiC enhanced both thermal conductivity and structural integrity, while the PCM core provided latent heat functionality. The findings highlight the potential of PCM/SiC aggregates for passive thermal regulation in buildings, offering a sustainable strategy to improve energy efficiency in cement-based materials without sacrificing mechanical performance.

Małek et al. [16] investigated the effect of silicon carbide (SiC) on the mechanical performance of concrete, focusing on compressive and tensile strength. SiC was added at dosages ranging from 5% to 15% by mass of cement. Compressive strength increased significantly, particularly at the 10% level, while tensile strength showed moderate improvement. These gains were attributed to SiC's high hardness and filler effect, which improved particle packing and reduced porosity. The study supports SiC as an effective additive for enhancing the mechanical properties of conventional concrete, especially in structural applications where increased compressive strength and material density are critical.

In addition to its exceptional increase is strength and durability, SiC impacts thermal conductivity and energy efficiency of cement-based composites. Yinfei et al. [3] explored the use of silicon carbide (SiC) as a thermally conductive additive to improve heat transfer in concrete layers used above floor heating systems. SiC significantly enhanced the thermal conductivity of the cement matrix, resulting in increased surface heating efficiency. The study concluded that SiC-modified concrete improves energy performance without compromising mechanical strength, making it a promising material for sustainable heating applications in building systems.

While SiC has been widely explored in conventional cement and mortar applications, Van den Heever et al. [17] investigated its influence on the 3D printability of cement-based materials, focusing on rheological behavior and buildability. SiC nanoparticles were added in contents up to 0.75% by weight of binder. At low dosages, SiC improved shape retention and buildability by increasing thixotropy and structural build-up, which are critical for maintaining geometry during layer-by-layer printing. However, higher concentrations led to excessive stiffening and reduced flowability. Rheological tests confirmed higher yield stress and viscosity, while mechanical tests showed that interlayer bonding was preserved or improved at optimal dosages. These results suggest that SiC nanoparticles, when used in controlled amounts, can enhance the printability and structural reliability of 3D-printed cementitious components, supporting their application in automated construction technologies.

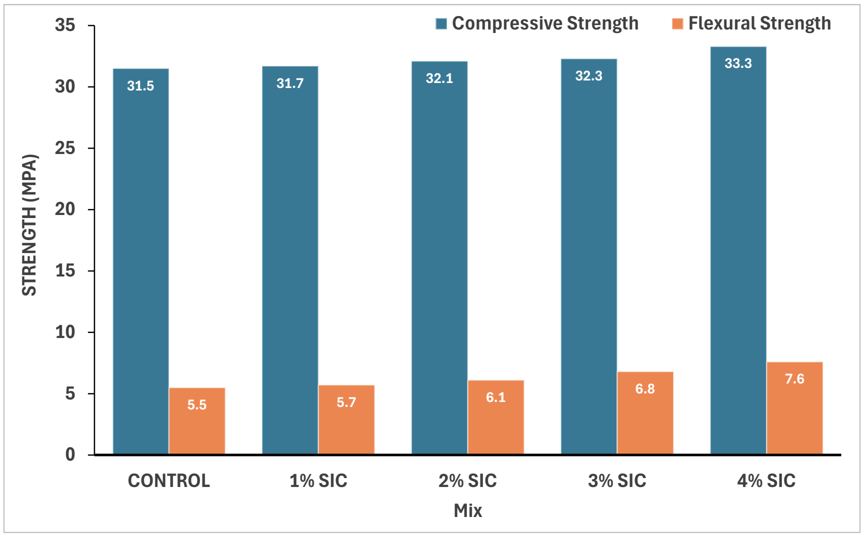

Fig. 2. Compressive and flexural strengths for sic as an additive in concrete [14]

7. Durability and long-term performance

When concrete is faced with severe conditions such as chemical waste, durability is typically reduced. Jeon et al. [18] conducted a study replacing 3%, 5%, 7%, and 10% of fine aggregates, by weight. The samples were cured for 3, 7, and 28 - days. After curing, they were immersed in a sulfuric acid solution and evaluated based on compressive strength change. The experimental results showed that SiC-enhanced mortars exhibited reduced mass loss and less surface degradation after immersion in sulfuric acid compared to control samples. The dense microstructure and chemical inertness of SiC particles helped resist acid penetration and reduced the formation of gypsum and ettringite, which are typically associated with sulfate attack. SEM and XRD analyses confirmed that the inclusion of SiC mitigated microstructural damage and maintained matrix cohesion under aggressive chemical conditions. Compressive strength retention was also higher in SiC-modified specimens over prolonged exposure. The study found that SiC plays an important role by filling the pores inside cement composites and densifying the microstructure [18]. The study concludes that SiC is an effective additive for improving the acid resistance of cementitious materials, making it suitable for applications in chemically aggressive environments such as sewage systems, industrial floors, and wastewater infrastructure.

In freeze-thaw conditions, SiC has also shown notable benefits. Woo et al. [19] investigated the effect of SiC on freeze-thaw durability by subjecting modified concrete mixes to rapid freeze-thaw cycles. Their results showed reduced surface scaling, improved dynamic modulus retention, and fewer microcracks in SiC-containing samples. Enhanced thermal conductivity was found to reduce internal stress by promoting more uniform temperature distribution during freezing and thawing. Microstructural analysis further revealed improved integrity and reduced cracking. These findings suggest that SiC incorporation can significantly improve durability in cold climates and temperature-variable environments.

The improved performance of SiC-modified cementitious materials across both chemical and thermal exposures is closely linked to its role in densifying the matrix and reducing pore connectivity, making it a promising additive for infrastructure exposed to aggressive or fluctuating environmental conditions.

8. Discussion

The integration of silicon carbide (SiC) into cementitious systems demonstrates clear performance improvements in mechanical, thermal, and electrical properties; however, these benefits are highly dependent on particle size, dosage, and dispersion effectiveness. Numerous studies have shown that finer SiC particles, approximately 80 nm in size, promote uniform distribution and improved interfacial bonding, resulting in enhanced thermal conductivity and mechanical strength [3, 5]. On the other hand, high replacement levels—typically exceeding 12–15 percent by weight of cement—have been associated with particle agglomeration, increased porosity, and reduced workability [4, 13]. An optimal dosage range between 8–12 percent has been identified in several studies as sufficient to enhance composite performance without adversely affecting mixture quality [13, 14].

In terms of durability, SiC-modified concretes have demonstrated notable improvements in chemical resistance and freeze-thaw stability, making them suitable for aggressive environments such as industrial floors, wastewater systems, and cold-weather infrastructure [18, 19]. The material's high thermal conductivity also supports its use in functional applications including heated pavements, geothermal energy systems, and thermally responsive building components [9, 10, 15]. Despite these advantages, practical limitations remain. The angular morphology and high surface area of SiC particles tend to reduce slump and complicate mixing, raising concerns about scalability with standard casting and pumping techniques [4, 13]. Without effective dispersion strategies and admixture optimization, issues such as void formation and poor interfacial bonding may compromise both structural and functional performance. Researchers such as van den Heever et al. [17] and Idrees et al. [14] have emphasized the need for advanced dispersion methods and mix design optimization to overcome these challenges.

From an economic standpoint, the high cost associated with high-purity SiC presents a significant barrier to its widespread implementation in conventional construction applications. While its incorporation may be justified in high-value contexts—such as military infrastructure, smart systems, and energy-efficient buildings—the overall feasibility for general-purpose concrete remains limited unless cost-effective alternatives, such as industrial by-products or hybrid material formulations, are adopted [20]. Additionally, despite SiC's potential to partially replace clinker-based binders and contribute to reduced cement consumption, its energy-intensive production process may offset potential environmental benefits if not sustainably sourced. As such, comprehensive life cycle assessments and cost-benefit analyses are critical for evaluating the viability of SiC in sustainable construction and ensuring its responsible and targeted use [20].

Lastly, while laboratory findings on SiC-enhanced concretes are promising, real-world validation remains limited. Long-term studies examining behavior under environmental stressors such as carbonation, ultraviolet radiation, chloride ingress, and thermal cycling are needed. Field-scale trials and service-life modeling will be critical to bridge the gap between controlled experiments and practical deployment in resilient, high-performance infrastructure.

9. Future research

Future research on SiC in construction applications should focus on advancing its practical implementation through comprehensive life cycle cost analyses (LCCA) and environmental life cycle assessments (LCA) to evaluate its economic and ecological feasibility, particularly for high-performance applications such as military pavements, geothermal infrastructure, and smart building systems. Optimizing mix designs continues to be a priority, including the incorporation of supplementary cementitious materials (SCMs) and the development of specialized admixtures to enhance workability, reduce particle agglomeration, and improve dispersion. In addition, long-term durability assessments under realistic environmental conditions, such as chloride ingress, carbonation, ultraviolet exposure, and thermal fatigue, are essential to determine the material's reliability in harsh service environments. Field-scale validation of structural elements like beams, slabs, and columns will be crucial for understanding real-world performance, especially in conductive or multifunctional systems. The integration of SiC into advanced construction technologies, including 3D printing, also warrants investigation to assess buildability, interlayer bonding, and structural integrity at scale. Lastly, SiC's thermoelectric and semiconductive properties open promising pathways for multifunctional infrastructure, such as self-heating pavements, electromagnetic shielding, and self-sensing components, positioning it as a strategic material for next-generation sustainable and intelligent construction.

10. Conclusion

The incorporation of silicon carbide (SiC) into cement-based materials offers significant potential for developing high-performance, multifunctional concretes that align with the evolving needs of modern construction. SiC has been shown to improve a range of properties, including mechanical strength, thermal and electrical conductivity, freeze-thaw resistance, and chemical durability, making it particularly suitable for advanced applications such as energy-efficient pavements, thermoelectric systems, and protective structures in aggressive environments. Its compatibility with emerging technologies like 3D printing further supports its role in next-generation construction practices. However, practical implementation is challenged by reduced workability, dispersion difficulties, material cost, and the variability of optimal dosages depending on the application. These limitations highlight the need for tailored mix designs, advanced admixture solutions, and careful consideration of project-specific requirements. Realizing the full benefits of SiC in concrete will depend on continued interdisciplinary research, including field trials, long-term performance evaluations, and life cycle cost assessments, to facilitate its transition from a promising laboratory material to a mainstream component in resilient and sustainable infrastructure.

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