



Donma-Çözülme Etkisi Altında Yapısal Güçlendirme Uygulamalarında Kullanılan SIMCON'un Performansı

Performance of SIMCON in Structural Retrofitting Under Freeze-Thaw Exposure

Ömer Karagöz^{1*}, Serdal Ünal², Kerem Aybar³, Mehmet Canbaz⁴

^{1,2,4} Eskişehir Osmangazi University, Civil Engineering Department, Eskişehir, Türkiye

³ Eskişehir Osmangazi University, Metallurgical and Mat. Eng. Dep., Eskişehir, Türkiye

ÖZET

Bu çalışma, portland çimentosu (CEM I 42.5R) ve kalsiyum alüminat çimentosunu (CAC) bağlayıcı olarak kullanarak üretilen çimento bulamacı emdirilmiş ağ şeklinde lif içeren beton (SIMCON) kompozitlerinin donma-çözülme (D-Ç) dayanımı ve mekanik performansını incelemektedir. SIMCON numuneleri, kontrollü olarak hazırlanmış çimento hamurlarının rastgele yerleştirilmiş çelik lif ağlarına emdirilmesiyle üretilmiştir; bu sayede daha iyi lif dağılımı ile çimento – çelik lif arasındaki bağın ve yük transferinin geliştirilmesi hedeflenmiştir. Numuneler 0, 15 ve 30 D-Ç çevrimine tabi tutulmuş ve birim hacim ağırlığı, ultrasonik geçiş hızı (UPV), eğilme dayanımı ve basınç dayanımı açısından değerlendirilmiştir. Sonuçlar, çevrim sayısının artmasıyla tüm özelliklerde bozulma olduğunu göstermiş; ancak CAC esaslı kompozitlerin CEM I içeren muadillerine kıyasla daha iyi performans gösterdiği görülmüştür. 30 çevrim sonunda, CAC numuneleri %54 oranında daha yüksek basınç dayanımı elde etmiş ve UPV ile eğilme dayanımında daha yavaş bozulma göstermiştir. CAC'nin üstün performansı, daha yoğun ve kararlı mikro yapısına ve iç çatlaklara ve neme karşı üstün direncine atfedilmiştir. Bu bulgular, uzun ömürlü dayanımın kritik olduğu zorlu çevresel koşullara maruz altyapı ve güçlendirme uygulamalarında SIMCON için CAC'nin umut vadeden bir bağlayıcı olduğunu göstermektedir.

Anahtar Kelimeler: SIMCON, Donma-Çözülme Dayanımı, Kalsiyum Alüminat Çimentosu (CAC), Lifli Beton Kompozitler, Yapısal Güçlendirme Malzemesi

ABSTRACT

This study investigates the freeze-thaw (F-T) durability and mechanical performance of Slurry Infiltrated Mat Concrete (SIMCON) produced with two different binders, Portland cement (CEM I 42.5R) and calcium aluminate cement (CAC). SIMCON composites were fabricated by infiltrating cement pastes into randomly oriented steel wool mats, aiming for improved fiber distribution and matrix-reinforcement interaction. Specimens were subjected to 0, 15, and 30 F-T cycles and evaluated on the basis of unit weight, ultrasonic pulse velocity (UPV), flexural strength, and compressive strength. The results showed that all properties deteriorated with increasing number of cycles; however, CAC-based composites consistently outperformed their CEM I counterparts. After 30 cycles, CAC specimens retained 54% higher compressive strength and exhibited slower deterioration rates in UPV and flexural strength. The superior performance of CAC is attributed to its denser, more stable microstructure and its improved resistance to internal cracking and moisture damage. These findings demonstrate that CAC is a promising binder for SIMCON in infrastructure and retrofit applications exposed to harsh environmental conditions where long-term durability is critical.

Keywords: Slurry-infiltrated Mat Concrete (SIMCON), Freeze-Thaw Durability, Calcium Aluminate Cement (CAC), Fiber-Reinforced Cement Composite, Retrofitting Material

Başvuru: 06.08.2025 Son Revizyon: 08.09.2025 Kabul: 08.09.2025

Doi: 10.51764/smutgd.1759647

^{1*}Sorumlu yazar: E-mail: okaragoz@ogu.edu.tr; ORCID: 0000-0002-3755-8345

² E-mail: serdalunall@gmail.com; ORCID: 0000-0002-5200-9969

³ E-mail: kaybar@ogu.edu.tr; ORCID: 0000-0001-6347-843X

⁴ E-mail: mcanbaz@ogu.edu.tr; ORCID: 0000-0002-0175-6155

1. INTRODUCTION

Structural deterioration due to environmental stressors is a determining aspect of the long-term safety and durability of aging infrastructure. Among these stressors, freeze-thaw (F-T) cycles are most severe in cold and temperate climates, where cyclic freezing and thawing of pore water in concrete can lead to progressive microcracking, mechanical weakening, and eventual structural failure (Canbaz & Albayrak, 2018; Fagerlund, 1977; Powers, 1945). Retrofits of existing structures in these climates demand composite materials with superior mechanical functionality and improved durability against cyclic thermal and moisture-driven damage.

Slurry Infiltrated Mat Concrete (SIMCON) is a type of high-performance fiber-reinforced cement composite (HPFRCC) that consists of networked steel fibers infiltrated with a flowable cementitious binder. This unique microstructure enables SIMCON to possess excellent tensile capacity (Murakami & Zeng, 1998), flexural strength (Bayasi & Zeng, 1997), crack resistance, and energy absorption (Li, 2003). Due to its densified matrix and efficient fiber distribution, SIMCON has been seen as a good potential candidate for structural retrofitting (J. Zeng, 2000; Qanber et al., 2023), particularly in instances where enhanced post-cracking behavior and long-term durability are favorable (Balamuralikrishnan & Jeyasehar, 2009; Jeyasehar & Ravichandran, 2013; Pyo et al., 2015). Even researchers suggested design guidelines for structural retrofit with SIMCON (E. Dogan et al., 2000). However, its freeze-thaw behavior, especially when used in repair applications, is still not well characterized. Freeze-thaw resistance of cementitious materials is governed to a large extent by the stability and porosity of the binder matrix, affecting both water ingress and internal stress development on phase change (Balaguru & Ramakrishnan, 1986). While ordinary Portland cement (CEM I) is widely used in SIMCON production due to its high strength and general-purpose applicability, it is known to be susceptible to microcracking and degradation upon cyclic freezing. In comparison, CAC is a fast-setting, high early-strength, and chemically stable cement and thus a very good candidate for use in aggressive environments (Scrivener, 2003). CAC forms denser, more crystalline hydration products with reduced permeability, and therefore may be able to impart better resistance to F-T cycles.

This study aims to compare and evaluate the mechanical and durability performance of SIMCON composites produced using two binder systems, CEM I 42.5R and CAC, under the action of repeated freeze-thaw exposure. While SIMCON has been studied for its mechanical properties and retrofitting potential, very limited research has addressed its behavior under freeze-thaw cycles, despite this being a critical durability factor for cold and variable climates. To address this gap, samples were prepared by the infiltration of tightly controlled cement pastes into randomly oriented steel wool mats with the prospect of achieving uniform fiber dispersion. Physical and mechanical properties, such as unit weight, UPV, flexural strength, and compressive strength, were tracked for 0, 15, and 30 freeze-thaw cycles. The results illustrate significant differences in the deterioration of the two binder systems, offering an understanding of the suitability of either system for structural retrofitting in cold and variable climates.

By systematically investigating the interaction of binder type, steel-matrix bond, and freeze-thaw durability, this study provides original experimental evidence on an underexplored aspect of SIMCON performance and contributes to the development of sustainable composite applications for infrastructure exposed to severe climatic conditions.

2. MATERIAL AND METHOD

2.1 Materials

In the production of SIMCON, binder materials included plain normal Portland cement CEM I 42.5R and CAC, with their properties detailed in Table 1. While CEM I 42.5R was selected as a high-strength, general-purpose binder, CAC was chosen for its rapid setting characteristics and superior resistance to freeze-thaw cycles and other aggressive environmental conditions.

Table 1. Properties of cements used in production

	CEM I, %	CAC, %		CEM I	CAC
SiO ₂	19,2	3,60	Density, g/cm ³	3,09	3,25
Al ₂ O ₃	4,56	39,80	Specific Surface, cm ² /g	3590	3000
Fe ₂ O ₃	3,09	17,05	Initial Setting, min	163	280
CaO	62,9	36,20	Final Setting, min	228	295
MgO	1,88	0,65	Expansion, mm	1	1

K ₂ O	0,63		Compressive strength, MPa	
Na ₂ O	0,31		6 hours	- 47
SO ₃	3,21	0,04	7 days	36,5 -
LOI	3,8	0,30	28 days	52,1 -

The mixing water used in the experiments was tap water from Eskişehir, with properties detailed in Table 2, and was selected as the standard mixing water.

Table 2. Properties of the the mix water

Chemical Content, mg/l						Physical Properties	
Al	0,04	Cu	0,016	Ni	5,07	Conductivity, μ S/cm	628
NO ₃	11,1	Fe	0,007	K	6,8	Hardness, Fd0	30,11
NH ₄	0,06	Mn	0,015	As	1,19	pH	7,35

As the network-form steel fiber reinforcement, Rota brand steel wool with properties detailed in Table 3 was utilized. The steel wool was procured from the Arı Boya company and selected to enhance the structural durability and mechanical performance of the SIMCON composite

Table 3. Mechanical properties of the steel mats

Average thickness, mm	0.03-0.08
Composition	18 Cr 10 Ni
Loose unit weight, g/cm ³	0.055
Thermal and electrical conductivity	high
Corrosion resistance	high

To enhance the consistency of the binder paste, the superplasticizer Optima 100, produced by CHRYSO and whose properties are detailed in Table 4, was employed. This admixture was selected to improve workability, reduce water demand, and ensure uniformity of the mixture.

Table 4. Properties of the admixture

Appearance	Color	Cl ⁻ , %	Specific gravity	pH
liquid	yellow	< 0,1	1,06	4

2.2 Method

In the production of SIMCON, binder pastes were meticulously prepared according to the water-to-binder ratios presented in Table 5. The consistency of these pastes is a critical parameter for ease of application and uniform fiber dispersion; thus, viscosities were measured using a viscometer. For mixtures containing CEM I cement, fluid consistency was achieved at a fixed water-to-cement ratio through the addition of superplasticizers at dosages recommended in Table 5. However, due to the lack of chemical compatibility between the superplasticizers and CAC, increased water content was necessary to achieve the desired workability in CAC-based mixtures. This adjustment resulted in higher water-to-binder ratios for CAC mixes compared to those with CEM I. The binder paste viscosity was controlled between 5 and 10 Pa·s at 100 rpm, ensuring optimal consistency for processing and homogeneous fiber distribution within the mold. Maintaining this controlled viscosity facilitates the placement of the composite without damaging the fiber network, thereby positively influencing the mechanical properties of the final product.

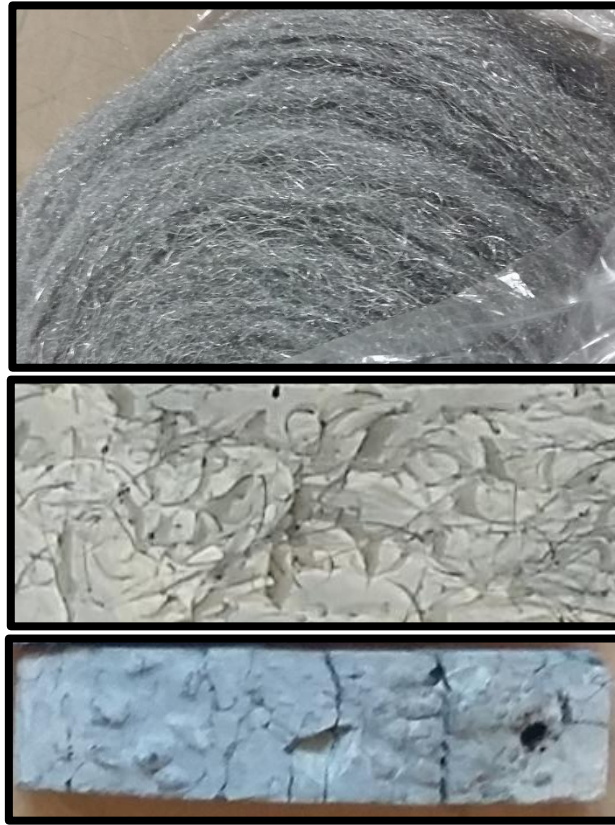


Figure 1. Steel mat used in SIMCON, production, and a specimen

Prismatic molds measuring 4×4×16 cm were initially filled with network-patterned steel fibers placed freely without compaction to ensure a uniform and random distribution of fibers within the mold, promoting effective fiber interlocking. Subsequently, a cement paste with a precisely controlled consistency was carefully poured over the fibers to maintain the integrity of the fiber network. To achieve homogeneous consolidation and minimize entrapped air voids, the specimens underwent vibration using a table vibrator, followed by surface leveling with a trowel. This production method allows for optimal fiber distribution within the composite without disrupting the network structure. Images illustrating the production process are presented in Figure 1. The binder-to-fiber ratios employed in the specimens are detailed in Table 5.

Table 5. Mixing ratio of samples components

Binder	Water/binder	Steel Mat/Binder	Admixture/Binder
CEM I	0.325	0.05	0.02
CAC	0.400	0.05	-

The specimens were removed from their molds 24 hours after casting and subsequently subjected to a 28-day curing process in a lime-saturated water bath under standard conditions to ensure optimal hydration. After curing, the samples were exposed to a series of freeze-thaw cycles to evaluate their resistance to environmental deterioration. Freeze-thaw cycles were performed by freezing water-saturated samples at -20 °C for at least two hours in a deep freezer and then thawing them in water at +20 °C. The temperature-controlled resistance curing tank maintained a constant temperature of +20 °C. As Figure 2 shows, the annual number of freeze-thaw cycles can reach 30. Therefore, 15 and 30 cycles were selected. We measured the dimensions, weights, and UPV of control samples that completed the cycle counts and were not subjected to freeze-thaw cycles. Subsequently, three-point flexural tests were conducted to assess the flexural strength of the specimens. In this test, the load was applied concentrically at the midpoint of the specimen, supported at two ends, enabling the measurement of the material's flexural capacity. After fracture, rigid plates measuring 4×4 cm were placed in alignment above and below the broken surfaces to perform compressive strength tests, aimed at evaluating the residual compressive resistance of the fractured sections. Both flexural and compression tests were repeated on at least three specimens to ensure the reliability and repeatability of the experimental results. Additionally, physical properties such as unit weight and UPV were recorded to correlate with the mechanical performance and facilitate comprehensive analysis.

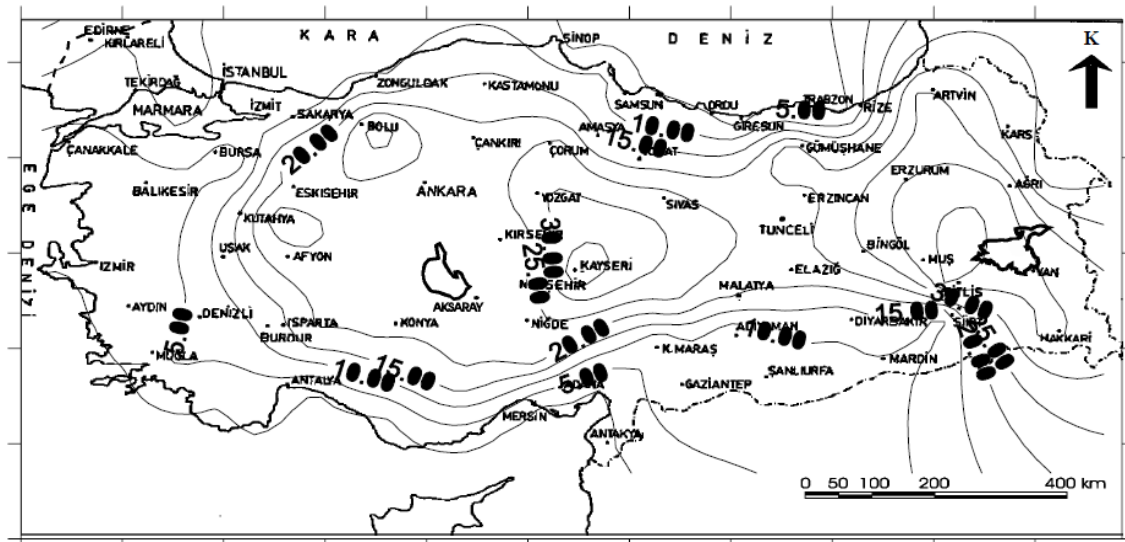


Figure 2. Map of Turkey's annual freeze-thaw cycle (Canbaz & Albayrak, 2018)

3. FINDINGS AND DISCUSSION

Figure 3 shows the unit weight results of SIMCON samples subjected to varying numbers of freeze-thaw cycles. According to the obtained data, the unit weight of both CEM I and CAC-bound samples decreased with an increase in the number of cycles. This indicates that freeze-thaw cycles negatively affect the microstructure of SIMCON, increasing the void ratio and reducing the material's density. The unit weight value of CEM I-bound samples decreased from 2.13 kg/dm^3 to 2.06 kg/dm^3 from the beginning to the 30th cycle, showing a loss of approximately 3.36%. Similarly, the initial value of 2.23 kg/dm^3 in CAC-bound samples decreased to 2.12 kg/dm^3 by the 30th cycle, resulting in a loss of approximately 4.93%. However, the loss observed in the first 15 cycles in the CAC group (approximately 4.48%) slowed significantly in the last 15 cycles, remaining at 0.47%. This suggests that structural voids form more rapidly in the initial cycles of CAC-bonded systems but that the degradation rate decreases after a certain number of cycles. In conclusion, freeze-thaw cycles were observed to reduce the unit weight in both binder systems, but the reduction was more pronounced in CAC-containing samples.

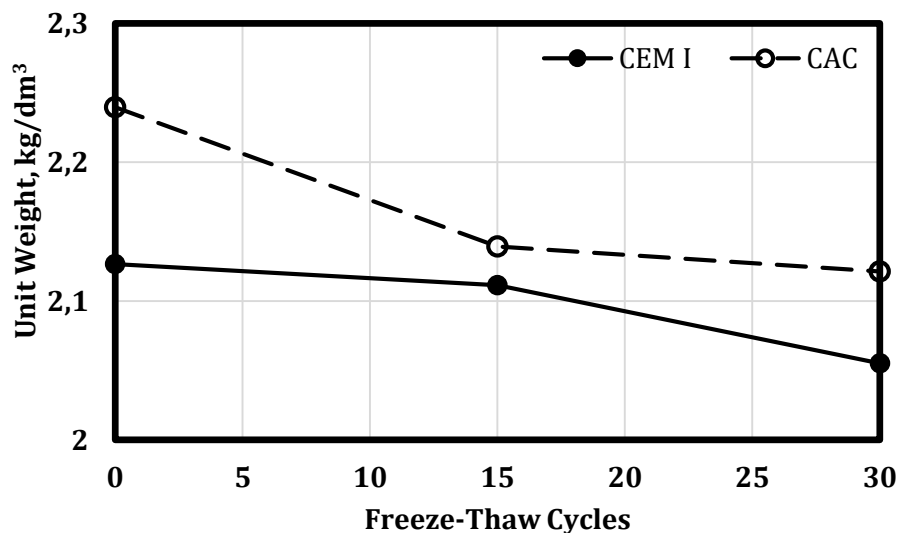


Figure 3. Unit weight of SIMCON specimens

Figure 3 shows the UPV values of SIMCON samples that were subjected to different freeze-thaw cycles. UPV is commonly used in durability analyses as an indicator of microstructural continuity, density, and crack formation within a material. The results indicate that an increase in freeze-thaw cycles reduces UPV in CEM I and CAC-bound

SIMCON samples. This suggests that microcracks and voids formed in the material due to the freeze-thaw effect hinder the passage of sound waves.

In CEM I-bound samples, UPV decreased from 3.03 km/s to 2.69 km/s after 15 cycles and to 2.30 km/s after 30 cycles. These values correspond to an 11.22% decrease by the 15th cycle and a 24.09% total decrease by the 30th cycle. This decrease suggests that the CEM I-based structure is less resistant to water expansion during freezing and is therefore more susceptible to cracking. Cracking of the cement paste may have caused adhesion losses at the steel-matrix interface, resulting in more pronounced discontinuities. In the CAC-bonded sample group, the initial value of 3.30 km/s decreased to 3.03 km/s by the 15th cycle and to 2.68 km/s by the 30th cycle. In this binder group, the UPV decreased by approximately 8.18% in the 15th cycle and by 18.79% in the 30th cycle. These results suggest that the CAC-based binder develops a more resilient internal structure in response to freeze-thaw conditions. CAC, which has a high alumina content, forms a denser, more chemically stable structure in terms of hydration products. This limits crack formation and affects sound wave transmission relatively less.

Comparative evaluation revealed that the continuity and internal integrity of both binders deteriorated as the number of cycles increased, as reflected in the UPV values. However, the decrease in UPV values of SIMCONs produced with CAC remained lower compared to CEM I, indicating that systems containing CAC are more resistant to freeze-thaw damage and can maintain structural continuity longer. Considering the significant effect of uniform distribution of steel mats and steel-matrix adhesion on UPV, the binder type's contribution to microstructural properties further enhances the significance of these results.

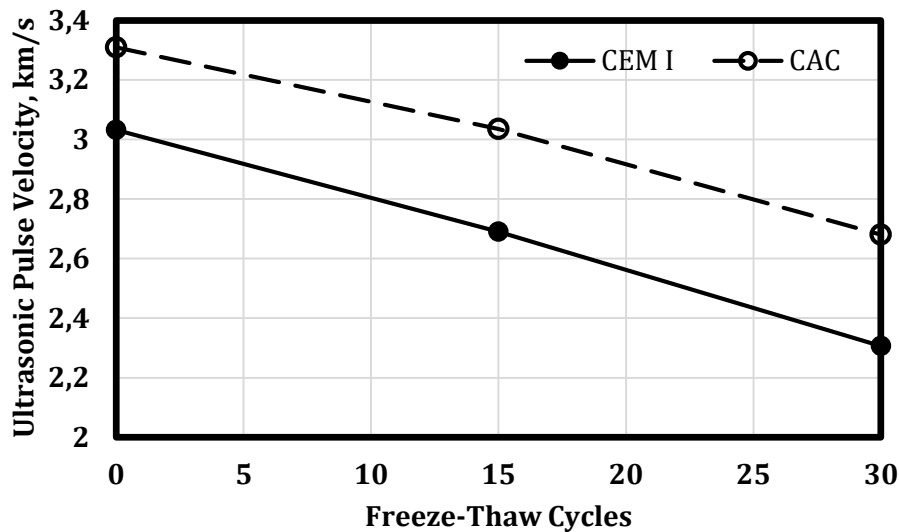


Figure 4. UPV of SIMCON specimens

Figure 5 shows the flexural strength of SIMCON samples subjected to different numbers of freeze-thaw cycles. Flexural strength is an important mechanical property that reflects the effectiveness of the steel-matrix interaction as well as the material's resistance to microcracking, particularly in steel-reinforced cementitious composite materials. As the number of freeze-thaw cycles increases, it is observed that the flexural strength of both CEM I and CAC-bonded SIMCON samples decreases. This can be attributed to an increase in microcracks in the cement matrix, particularly at the interface between the steel mats and the matrix. There is also a loss of adhesion and disruption of mechanical continuity as the number of cycles increases.

Initially, CEM I-based samples exhibited a flexural strength of 19.67 MPa. This value decreased to 18.65 MPa (a 5.2% reduction) after 15 cycles, and then to 16.40 MPa (a 16.65% total reduction) after 30 cycles. This decrease indicates that the CEM I-based matrix cannot maintain its structural integrity against the internal pressure generated during freezing, gradually losing its contribution to the load-bearing capacity of the steel mats. Conventional Portland cements have high water absorption tendencies and cracking potential and are the focal point of early deterioration in steel-reinforced systems under freeze-thaw effects. Micro-cracks around the mats, in particular, weaken the steel-matrix interaction, causing a decrease in flexural strength. The CAC-bonded samples initially exhibited an initial flexural strength of 20.45 MPa. This value decreased to 19.23 MPa (a 5.96% decrease) after 15 cycles and to 17.98 MPa (a 12.07% total decrease) after 30 cycles. The rate of decrease in flexural strength remained lower than that of the CEM I group, which further confirms that the CAC binder forms a microstructure that is more resistant to freeze-thaw cycles. The hydration products of CAC cements are more compact and crystalline, making them more stable against environmental effects and less prone to void formation. This ensures that the bond between the steel mats and the matrix remains intact for a longer period of time, thereby limiting the

loss of flexural strength.

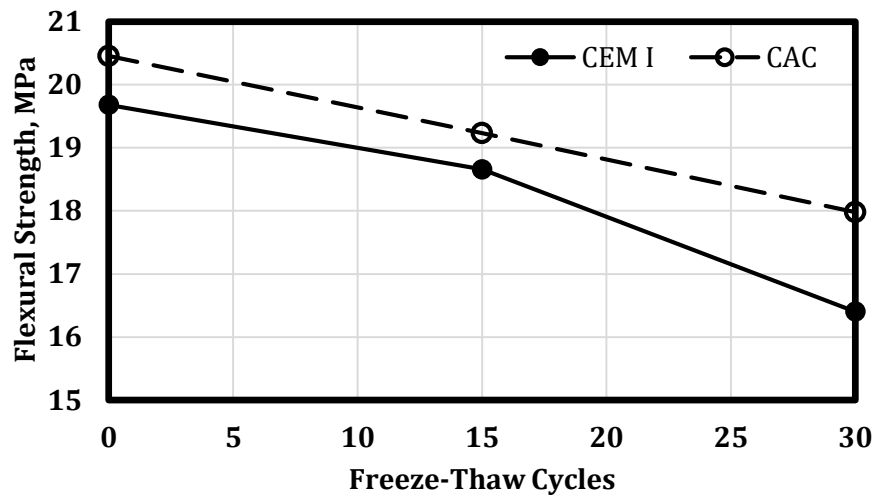


Figure 5. Flexural strength of SIMCON specimens

In conclusion, while both binder systems showed a tendency for flexural strength to decrease with cycles, CAC-based SIMCON samples demonstrated superior performance in terms of initial strength and resistance to cycling. These results highlight the impact of freeze-thaw cycles on the interfacial behavior of steel-reinforced cement composites and underscore the critical role of binder selection in durability performance.

Figure 6 shows the compressive strength results of SIMCON samples subjected to different freeze-thaw cycles. Compressive strength is a critical mechanical parameter that reflects the durability and microstructural integrity of the matrix and steel-matrix interface in cementitious composite materials. According to the obtained data, a significant decrease in compressive strength was observed in both CEM I- and CAC-bonded SIMCON samples as the number of cycles increased. However, CAC-bonded specimens consistently exhibited higher compressive strength values than CEM I specimens, and this difference became more pronounced with each additional cycle.

The compressive strength of 42.56 MPa measured initially in CEM I-bonded samples decreased to 32.30 MPa (24.15% decrease) after 15 cycles and to 27.17 MPa (36.15% total decrease) after 30 cycles. This decrease indicates that freeze-thaw cycles cause serious microcracks and voids in the classic Portland cement matrix, significantly reducing the structure's load-bearing capacity. Despite the contribution of the mats, the progression of damage within the matrix leads to critical reductions in compressive strength.

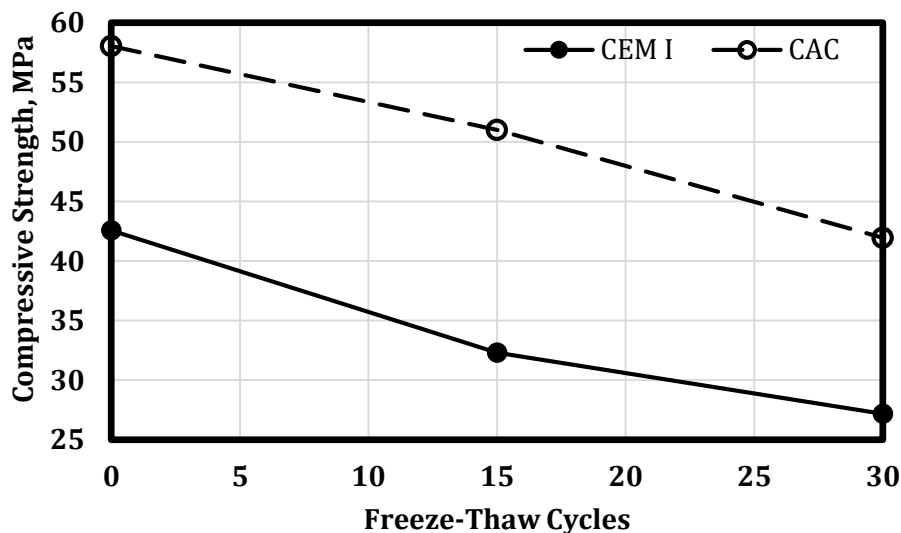


Figure 6. Compressive strength of SIMCON specimens

CAC-bonded specimens exhibited a very high initial compressive strength of 58.04 MPa at 0 cycles. This value decreased to 50.99 MPa (12.17% decrease) at 15 cycles and to 41.95 MPa (27.74% total decrease) at 30 cycles.

Although a decrease was observed in the CAC group, both the initial strength and the durability after cycles remained higher compared to the CEM I group. This indicates that the dense crystalline structure and chemical stability of CAC hydration products create a matrix that is more resistant to freeze-thaw effects, thereby allowing the steel-matrix interaction to remain healthy for a longer period of time. Additionally, CAC's lower water/binder ratio and different microstructural development have increased durability by limiting void formation.

In conclusion, although freeze-thaw cycles led to a decrease in pressure resistance in both binders, SIMCON samples with the CAC binder demonstrated superior performance, particularly in terms of load-bearing capacity and durability, providing a strong basis for the preference of CAC in steel-reinforced composite materials under harsh environmental conditions.

Our results show that both binders experience density (unit-weight) and UPV reductions with freeze-thaw cycling, reflecting classical frost damage mechanisms - progressive saturation, microcracking, and porosity growth - described by Powers (Powers, 1945) and by the critical-saturation framework of Fagerlund (Fagerlund, 1977). Notably, CAC-SIMCON exhibits smaller relative losses in UPV, flexural, and compressive strength than CEM I-SIMCON. This trend is consistent with the mechanics of SIMCON reported by Bayasi & Zeng and Murakami & Zeng (Bayasi & Zeng, 1997; Murakami & Zeng, 1998) where sustained steel-matrix stress transfer underpins flexural/tensile capacity, and with evidence that fiber reinforcement improves freeze-thaw durability in conventional systems. The comparatively lower degradation we observe for CAC-SIMCON is also aligned with CAC hydration literature, which indicates a denser, chemically stable hydrate assemblage that limits crack connectivity and transport under cycling (Scrivener, 2003). Together with prior applications of SIMCON in structural strengthening under monotonic and cyclic loads (Balamuralikrishnan & Jeyasehar, 2009; Jeyasehar & Ravichandran, 2013; Qanber et al., 2023), these results indicate that CAC-based SIMCON is particularly suitable for retrofitting and repair in cold and variable climates where freeze-thaw durability governs performance.

4. CONCLUSION

The key findings of the study are listed below:

- The results demonstrated that SIMCON composites produced with CAC exhibited superior durability and mechanical performance compared to those produced with ordinary Portland cement (CEM I 42.5R), particularly under freeze-thaw cycling. The denser and more stable microstructure of CAC-based matrices contributed significantly to this enhanced resistance.
- Unit weight values decreased with increasing freeze-thaw cycles for both binder types, indicating gradual internal deterioration and potential microcrack formation. However, CAC-based samples consistently maintained higher unit weight values, suggesting better structural integrity under environmental stress.
- UPV measurements revealed a clear reduction in internal cohesion with increased freeze-thaw cycles, especially in CEM I-based composites. CAC specimens retained relatively higher UPV values, which confirmed their lower porosity and more durable matrix-steel interface.
- Flexural and compressive strengths of all samples decreased as the number of freeze-thaw cycles increased; however, the rate of strength loss was significantly lower in CAC-based composites. In particular, the compressive strength of CAC specimens after 30 cycles remained approximately 54% higher than that of CEM I-based specimens, highlighting the superior freeze-thaw durability of the CAC system.
- The use of steel wool as a mesh-like reinforcement and the application of a superplasticizer contributed positively to the mechanical performance and workability of SIMCON mixtures. Nevertheless, binder type was found to be the most critical parameter influencing long-term durability under aggressive environmental conditions.

This study comparatively evaluated the performance of SIMCON composites produced with different binders under freeze-thaw conditions. The superior durability and mechanical properties of CAC-based composites suggest that this binder is highly suitable for use in structures exposed to harsh climatic conditions. The findings highlight that binder type plays a critical role in the long-term durability of steel-reinforced cementitious composites and contribute to the development of sustainable construction materials. Future studies could explore the long-term performance of SIMCON composites under combined environmental stressors, such as freeze-thaw cycles coupled with chemical attack or mechanical loading. Additionally, the effect of alternative fiber types and hybrid reinforcement strategies on durability and mechanical properties could be investigated to optimize SIMCON for diverse infrastructure applications.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Author Contribution Statement

The article is a result of joint work by the authors, each of whom contributed equally.

REFERENCES

- Balaguru, P. N., & Ramakrishnan, V. (1986). *Freeze-Thaw Durability of Fiber Reinforced Concrete*. 83(3). <https://doi.org/10.14359/10438>
- Balamuralikrishnan, R., & Jeyasehar, C. A. (2009). *Retrofitting of RC Beams with Externally Bonded Simcon Laminates*. 3(1). <https://doi.org/10.2174/1874149500903010034>
- Bayasi, Z., & Zeng, J. (1997). Flexural Behavior of Slurry Infiltrated Mat Concrete (SIMCON). *Journal of Materials in Civil Engineering*, 9(4), 194–199. [https://doi.org/10.1061/\(ASCE\)0899-1561\(1997\)9:4\(194\)](https://doi.org/10.1061/(ASCE)0899-1561(1997)9:4(194))
- Canbaz, M., & Albayrak, U. (2018). Properties of Ancient Style Handmade Clay Bricks Using Bottom Ash. *Anadolu University Journal of Science and Technology A- Applied Sciences and Engineering*, 19(1), 104–113. <https://doi.org/10.18038/aubtda.332855>
- E. Dogan, H. Hill, & N. Krstulovic-Opara. (2000). Suggested Design Guidelines for Seismic Retrofit with SIMCON and SIFCON. *SP-185: High-Performance Fiber Reinforced Concrete in Infrastructural Repair and Retrofit*, 185, 207–248. <https://doi.org/10.14359/5717>
- Fagerlund, G. (1977). The critical degree of saturation method of assessing the freeze/thaw resistance of concrete. *Matériaux et Construction*, 10(4), 217–229. <https://doi.org/10.1007/BF02478693>
- J. Zeng, P. K., and Z. Bayasi. (2000). Slurry Infiltrated Mat Concrete (SIMCON) for Rehabilitation of Bridges and Pavements. *ACI Symposium Publication*, 185. <https://doi.org/10.14359/5710>
- Jeyasehar, C. A., & Ravichandran, K. (2013). Cyclic behaviour of beam column joint retrofitted with SIMCON laminates. *Asian Journal of Civil Engineering*, 14(2), 269–288. SID. <https://sid.ir/paper/299021/en>
- Li, V. C. (2003). On Engineered Cementitious Composites (ECC): A Review of the Material and Its Applications. *Journal of Advanced Concrete Technology*, 1(3), 215–230. <https://doi.org/10.3151/jact.1.215>
- Murakami, H., & Zeng, J. Y. (1998). Experimental and analytical study of SIMCON tension members. *Mechanics of Materials*, 28(1–4), 181–195. [https://doi.org/10.1016/S0167-6636\(97\)00060-4](https://doi.org/10.1016/S0167-6636(97)00060-4)
- Powers, T. C. (1945). A Working Hypothesis for Further Studies of Frost Resistance of Concrete. *ACI Journal Proceedings*, 41(1). <https://doi.org/10.14359/8684>
- Pyo, S., Wille, K., El-Tawil, S., & Naaman, A. E. (2015). Strain rate dependent properties of ultra high performance fiber reinforced concrete (UHP-FRC) under tension. *Cement and Concrete Composites*, 56, 15–24. <https://doi.org/10.1016/j.cemconcomp.2014.10.002>
- Qanber, A. S. G., Yas, M. H., & Kadhun, M. M. (2023). Numerical and Experimental Behavior Analysis of Slabs Strengthened Using Steel Plates and Slurry-Infiltrated Mat Concrete (SIMCON) Laminates. *Infrastructures*, 8(5), 85. <https://doi.org/10.3390/infrastructures8050085>
- Scrivener, K. (2003). Calcium Aluminate Cements. In J. Newman & B. S. Choo (Eds.), *Advanced Concrete Technology 1: Constituent Materials*. Elsevier. ISBN: 978-0-08-048998-8