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Performance of Self-Compacting Concrete Mixed and Cured with Magnetized Water

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Abstract. This study investigates the effect of magnetized water (MW) on the mechanical and microstructural properties of self-compacting concrete (SCC). Four mixes with identical proportions were prepared to isolate the influence of MW at different stages: SCNTN (normal water used in both mixing and curing), SCNTM (normal water in mixing and MW in curing), SCMTN (MW in mixing and normal water in curing), and SCMTM (MW used in both mixing and curing). Compressive strength tests were conducted at 7 and 28 days, and microstructural characterization was performed using X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR). The results showed that using MW during mixing enhances early-age strength through improved dispersion and hydration of cement particles, while using MW during curing contributes more significantly to long-term hydration. The combined use of MW in both mixing and curing (SCMTM) achieved the highest strength values, with improvements of 25.8% at 7 days and 14.2% at 28 days compared to the control mix. Microstructural findings confirmed denser calcium–silicate–hydrate (C–S–H) gel formation and reduced unhydrated phases in MW-treated concrete. These results indicate that MW has a positive influence on both hydration and strength development in SCC.

Keywords: self-compacting concrete, magnetized water, mixing, curing process, compressive strength, XRD, FTIR

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1. Introduction

Self-compacting concrete (SCC) is a highly flowable and non-segregating material capable of consolidating under its own weight without external vibration. This property ensures excellent workability and enables efficient filling of complex or congested formwork. However, the overall performance of SCC is strongly influenced by the characteristics of its constituents, particularly the mixing and curing water, which play a crucial role in cement hydration, microstructural development, and strength gain [1-2]. Variations in water quality or treatment can significantly affect hydration kinetics and durability, motivating research into advanced methods to enhance the effectiveness of water in concrete technology [3-4].

One promising approach is the use of magnetized water (MW)[5], which has been reported to improve both the fresh and hardened properties of concrete by influencing the physicochemical behavior of water [6]. MW is produced by passing ordinary water through a magnetic field, which alters its molecular structure by breaking down large hydrogen-bonded clusters into smaller, more reactive ones [7]. These molecular changes decrease surface tension, enhance ion mobility, and improve the dispersion and wetting of cement particles [8-9]. Consequently, MW accelerates hydration reactions, promotes the formation of denser calcium–silicate–hydrate (C–S–H) gel, and enhances both early and long-term compressive strength [10]. Figure 1 illustrates the effect of the magnetic field on water molecules, highlighting the transformation from large, clustered groups in normal water to smaller, more active clusters in MW demonstrating the mechanism by which magnetized water enhances cement hydration and concrete performance [11-12].

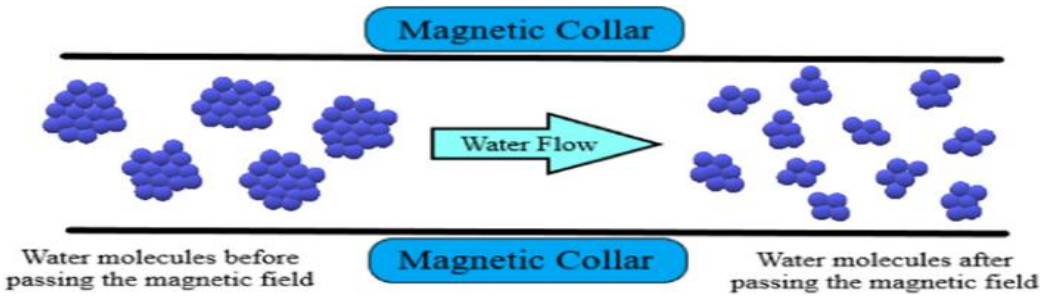

Figure 1. Effect of magnetic field on the structure of water molecules [12]

Previous studies have reported that using MW during mixing enhances compressive strength, reduces porosity, and results in a denser microstructure [13-15]. Similarly, employing MW during curing sustains hydration, minimizes microcracking, and improves long-term durability [16-18]. Analytical techniques such as X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) have confirmed these improvements, showing reduced calcium hydroxide peaks, enhanced silicate bonding, and a denser hydration network in MW-treated concretes.

Despite these encouraging findings, most existing research has focused on MW application in either mixing or curing separately, with limited comparative evaluation between the two stages. This gap in the literature leaves uncertainty regarding which stage contributes more effectively to performance enhancement. Addressing this question is vital for optimizing MW use and maximizing its practical benefits.

The present study conducts a comparative evaluation of SCC prepared with magnetized water used in the mixing stage, in the curing stage, and in both stages, alongside a control mix prepared with normal water. The main objective is to assess the compressive strength at 7 and 28 days to capture both early-age and long-term effects, to analyze hydration products and microstructural evolution through XRD and FTIR, and to determine whether MW applied during mixing or curing yields greater improvements in performance. By combining mechanical testing with microstructural characterization, this study provides new insights into the role of MW at different stages of SCC production. The outcomes are expected to clarify which stage, mixing or curing, offers superior enhancement in strength and hydration efficiency, and to deliver practical guidance for employing MW as a sustainable and efficient approach to improve the quality and durability of self-compacting concrete [19-21].

2. **Materials and methods**

2.1. Materials

Ordinary Portland cement (OPC) conforming to BS EN 197-1:2000 was used as the main binder. Crushed stone with a nominal size of 12–14 mm served as the coarse aggregate and was characterized in accordance with ASTM C136 , while natural sand was used as the fine aggregate. Both aggregates

were sieved, and prepared in a single batch to ensure uniformity throughout all mixtures. Aggregate properties, including specific gravity, water absorption, and abrasion resistance, were verified following ASTM C128 and ASTM C131. In addition, silica sand was incorporated as a micro-filler to improve particle packing density and minimize internal porosity. The chemical composition of OPC, presented in Table 1, indicated that calcium oxide (CaO) was the dominant constituent.

The mixing water used was either potable tap water (normal water, NW) or magnetized water (MW). MW was produced by passing tap water through a magnetic device generating a field intensity of approximately 1 Tesla. To ensure stable magnetization, the water was circulated through the magnetic field five consecutive times before mixing and continuously maintained in circulation during the curing stage (Table 2, Figure 2). This procedure ensured uniform exposure and prevented magnetic decay before use.

Table 1. Chemical compositions of Ordinary Portland cement.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	LOI
20.3	6.3	3.12	63.6	1.6	0.4	1.13

Table 2. Mechanical properties of the magnetic shaft device

Flow rate (m^3/h)	Inlet and outlet (mm)	Weight (Kg)	Magnet Power (Gauss)	Size(mm)
4.9	25	3	10000	76(Diameter) × 600(Height)

Figure 2. Water Magnetizer Shaft

2.2. Mix Proportions

Four concrete mixes were designed using self-compacting concrete (SCC) with magnetized water and SCC with normal water. The water-to-cement ratio was 0.42. Detailed proportions of cement, water, aggregates, silica sand, and superplasticizer are presented in Table 3.

Specimen Preparation and Casting

All dry materials, including cement, fine sand, silica sand, and coarse aggregates, were first mixed for approximately one minute in a rotary mixer to ensure uniform distribution. Subsequently, either normal water (NW) or magnetized water (MW) was gradually added over two minutes while mixing continued. The superplasticizer was introduced together with the final portion of water, and mixing proceeded for an additional three minutes to achieve complete homogeneity and the required flowability of the SCC.

The fresh properties of the mixes were evaluated according to EFNARC (2005) guidelines [22], including slump flow, and V-funnel flow, which indicated improved flow and segregation resistance for MW-based SCC compared with the control mix prepared using NW. The prepared mixtures were then cast into standard molds 150 mm cubes for compressive strength testing in accordance with BS EN 12390-3, while powdered samples obtained from broken specimens were used for XRD and FTIR

analyses (Figure 3).

To ensure consistency and enable a comparative evaluation, four SCC mixes with identical proportions were prepared, differing only in the type of water used during mixing and curing, as summarized in Table 3.

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Figure 3. Compressive strength test and FTIR test and XRD test

Table 2. Mix proportions of the concrete used in this study (per 1 m³).

Mix ID	Water Type for Mixing	Water Type for Curing	Cement (kg)	Water (kg)	Coarse Aggregate (kg)	Fine Sand (kg)	Silica Sand (kg)	Superplasticizer (kg)
SCNTN	Normal	Normal	390	163	822	668.5	286.5	7.8
SCNTM	Normal	Magnetized	390	163	822	668.5	286.5	7.8
SCMTN	Magnetized	Normal	390	163	822	668.5	286.5	7.8
SCMTM	Magnetized	Magnetized	390	163	822	668.5	286.5	7.8

2.3. uring Conditions

Curing was performed for 28 days under controlled laboratory conditions, with specimens fully immersed in either normal water (NW) or magnetized water (MW), according to their group designation. The curing tanks were maintained at 20 ± 2 °C. The use of MW was expected to promote further hydration and improve microstructural densification during curing due to its modified physicochemical properties. The curing setup is shown in Figure 4.

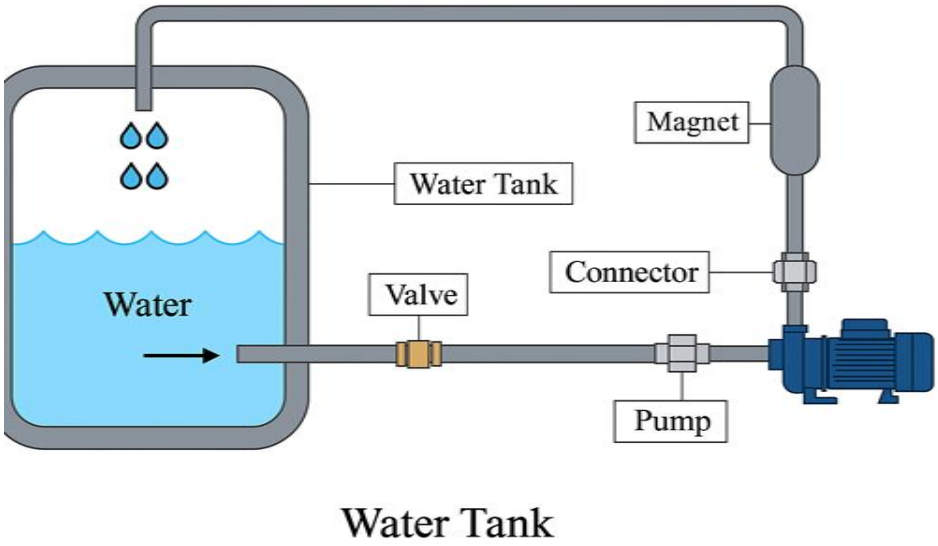

Figure 4. Curing System with Magnetic Water [19].

3. Results and discussion

3.1. Fresh properties of SCC

In this study, the fresh-state properties of the SCC were evaluated using slump flow, V-funnel, and L-box tests. The results are summarized in Table 4 and demonstrate good compliance with the EFNARC [38] guidelines for SCC performance.

Table 4 Fresh properties result of SCC

Mixes	Slump flow Dia (mm)	V-funnel Time (s)	L-box (h_2/h_1)
SN	700–740	9–11	0.85
SM	755–780	7–9	0.91
EFNARC[a]	550–850	9–25	0.8≤

[a] The European Federation of Specialist Construction Chemicals and SCC Systems.

The slump flow test results indicate that magnetized water positively influenced the workability of the concrete. As shown in Table 4, the SCC mix incorporating MW exhibited higher slump flow values (755–780 mm) compared to that mixed with NW (700–740 mm). Additionally, the time required for the concrete to spread to a diameter of 500 mm (T_{500}) was less than 5 seconds for the MW mix, whereas it exceeded 5 seconds for the NW mix. According to EFNARC classifications, slump flow values between 700–740 mm fall within class SF2 (660–750 mm), suitable for standard applications such as walls and columns, while values of 755–780 mm correspond to class SF3 (760–850 mm), indicating suitability for highly reinforced sections like deep beams, precast elements, and densely reinforced zones. The improved flowability observed with the MW mix can be attributed to enhanced water penetration through the cement hydration layer, likely due to structural changes in water molecules induced by magnetization. This finding is consistent with previous studies [7], [14], [26], which reported improved workability in concrete when MW is used.

Similarly, the V-funnel test was conducted to assess the viscosity and filling ability of the mixes and the results are shown in Table 4. EFNARC recommends a flow time between 6 and 12 seconds for optimal SCC performance. In this study, the NW mix exhibited flow times ranging from 9 to 11 seconds, while the mix with MW showed reduced flow times of 7 to 9 seconds, indicating lower

viscosity and improved flow efficiency. Both mixes fall within the VF2 classification, which aligns with the VS2 category based on slump flow. The reduction in flow time with magnetized water suggests a decrease in internal friction within the fresh mix, supporting earlier findings [3], [7], that magnetization reduces and enhances flow characteristics.

The L-box test results further corroborate the improvements in workability. The passing ability of SCC is evaluated through the blocking ratio (h_2/h_1), with EFNARC specifying a minimum value of 0.8 for adequate performance. Both mixes met this requirement; however, the mix with magnetized water achieved a higher ratio of 0.91 compared to 0.85 for the NW mix, demonstrating superior ability to flow through congested reinforcement. Despite the difference in performance, both mixes are classified under PA2, the standard category for passing ability.

3.2. Compressive Strength

The influence of magnetized water on the compressive strength development of self-compacting concrete (SCC) was evaluated at both early (7-day) and later (28-day) ages. Four mixes were investigated: the reference mix (SCNTN), prepared and cured with normal water; SCNTM, prepared with normal water and cured with magnetized water; SCMTN, prepared with magnetized water and cured with normal water; and SCMTM, prepared and cured with magnetized water. The compressive strength results of these mixes at 7 and 28 days are presented in Table 4, while the corresponding trends are illustrated in Figure 5.

Table 5. Compressive strength of self-compacting concrete with different magnetized water treatments at 7 and 28 days

Mix code	SCNTN MPa	SCNTM MPa	SCMTN MPa	SCMTM MPa
7 DAY	31.4	35.3	38.6	39.5
28 DAY	43.3	47.4	45.2	49.45

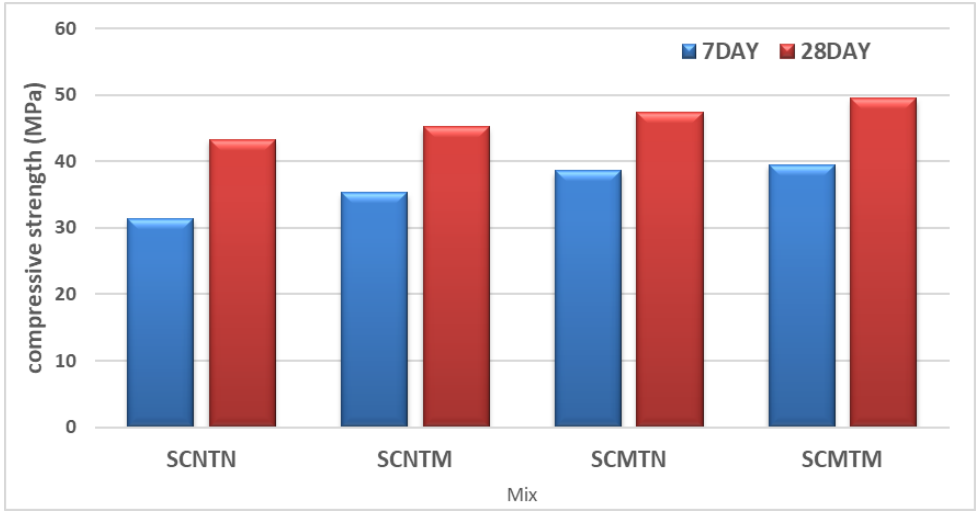

Figure 5. Compressive strength of self-compacting concrete with different magnetized water treatments at 7 and 28 days

At 7 days, the effect of magnetized water during mixing was particularly pronounced. The SCMTN mix reached 38.6 MPa, corresponding to a 22.9% increase compared to the control (31.4 MPa). In contrast, SCNTM (magnetized only during curing) achieved 35.3 MPa, a more modest 12.4% improvement. These findings are consistent with recent studies demonstrating that magnetized water

during mixing enhances early hydration by reducing molecular clustering, improving ion mobility, and promoting more uniform cement particle dispersion [12-14]. Abbas et al. [1] similarly attributed this early enhancement to denser C–S–H gel formation, which translates into higher early-age strength.

At 28 days, however, the benefits of magnetized water during curing became more evident. The SCNTM mix achieved 47.4 MPa, a 9.5% improvement over the control, whereas SCMTN recorded only 45.2 MPa, representing a 4.4% increase. This suggests that magnetized curing water sustains hydration reactions, reduces microcracking, and enhances long-term strength development [11-17]. Comparable results were reported by Elkerany et al. [10] and Hatem et al. [17], who found that magnetized curing water improves hydration efficiency and overall mechanical performance at later ages.

The highest strengths were obtained when magnetized water was employed in both mixing and curing. The SCMTM mix attained 39.5 MPa at 7 days (a 25.8% improvement) and 49.45 MPa at 28 days (a 14.2% improvement). This dual benefit reflects the synergy between accelerated early hydration during mixing and extended hydration during curing. Similar synergistic outcomes were observed by Ghorbani et al. [14] and ELShami et al. [11], where combined use of magnetized water resulted in superior compressive and flexural strengths.

Overall, these results highlight the significant potential of magnetized water to improve the mechanical performance of SCC. While magnetized water in mixing accelerates early hydration, its application during curing ensures prolonged hydration and microstructural refinement. For optimum strength development, employing magnetized water during both mixing and curing is strongly recommended.

3.3. X-ray diffraction (XRD)

Among the four prepared SCC mixes, two representative mixtures SCNTN (control, mixed and cured with normal water) and SCMTM (mixed and cured with magnetized water) were selected for detailed XRD analysis to compare the extreme conditions of water treatment. XRD was employed to characterize the crystalline phases within the hydrated cementitious matrix and to monitor the evolution of hydration products during curing [1-2]. The diffraction patterns provided insight into phase formation, hydration progress, and structural stability (Figure 6).

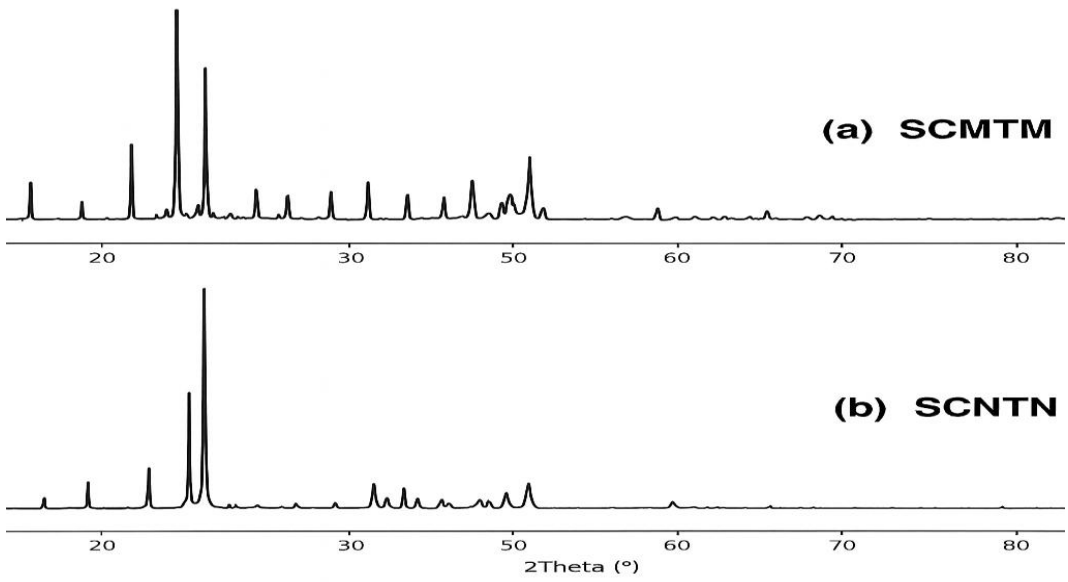

Figure 6. X-ray diffraction (XRD) patterns of self-compacting concrete samples: (a) SCMTM (mixed and cured with magnetized water) and (b) SCNTN (mixed and cured with normal water).

At ambient temperature (25 °C), both SCNTN and SCMTM exhibited characteristic reflections of hydrated and filler phases, including portlandite ($Ca(OH)_2$) with peaks near $2\theta \approx 18.0°$, 34.1°, and 47.1°; calcite ($CaCO_3$) at $2\theta \approx 29.4°$; and quartz (SiO_2) at $2\theta \approx 26.6°$. Minor peaks corresponding to dolomite ($CaMg(CO_3)_2$) and ettringite were also detected, reflecting contributions from filler materials and early sulfate hydration.

Semi-quantitative interpretation of peak intensities indicated that SCMTM achieved a higher degree of hydration than SCNTN. The MW-based mix contained approximately 10% portlandite and no detectable larnite (C_2S), while the control mix contained ~4% portlandite and ~6% unhydrated larnite. Additionally, SCMTM showed higher calcite (~30%) and lower dolomite (~53%) contents, which may indicate more extensive secondary reactions such as carbonation and partial dedolomitization. The sharper and more intense peaks observed in SCMTM, particularly for portlandite and calcite, demonstrate enhanced crystallinity and a higher degree of hydration associated with MW use [8].
These results are consistent with compressive strength data and with previous findings [19-20], confirming that magnetized water promotes improved ion mobility, accelerates hydration kinetics, and facilitates the formation of a denser and more stable microstructure.

3.4. Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra of the SCC samples (Figure 8) revealed distinct differences depending on whether magnetized water (MW) was used during mixing, curing, or both.

The SCNTM sample (Figure 8(a)) exhibited major absorption bands at 1415, 874, and 1007 cm^{-1}, with smaller peaks at 726, 712, and 799 cm^{-1}. The Si–O stretching band at 1007 cm^{-1} appeared weaker than that of SCMTM, while the stronger carbonate peaks indicated partial carbonation and an incomplete hydration process. These results suggest that magnetic curing alone enhances hydration but is less effective than the combined use of MW during both mixing and curing.

The SCMTN spectrum (Figure 8(b)) showed a main C–S–H band at 1008 cm^{-1} and carbonate absorptions at 1414 and 875 cm^{-1}, along with Si–O–Si bending vibrations at 526, 468, and 429 cm^{-1}. Although magnetic mixing promoted early hydration, the limited number and narrower width of absorption peaks suggested incomplete hydration compared with SCMTM, emphasizing the role of continuous curing with MW.

The control mix, SCNTN (Figure 8(c)), exhibited typical cementitious absorptions, including carbonates at 1414 and 874 cm^{-1} and Si–O bands at 1094 and 1008 cm^{-1}. Several broad peaks at 557, 529, 494, 478, and 463 cm^{-1} reflected the presence of unreacted phases and incomplete hydration. Without magnetic treatment, the cement matrix contained more unhydrated material, resulting in the weakest performance among all mixes.

The SCMTM sample (Figure 8(d)) exhibited the most complex spectrum with multiple sharp peaks. A strong Si–O absorption band appeared at 1003 cm^{-1} with high intensity, accompanied by bending vibrations at 463 and 428 cm^{-1} and a carbonate-related band at 1413 cm^{-1}. The dominant Si–O band and reduced carbonate peaks suggested the formation of abundant C–S–H gel and limited carbonation. This mix displayed the highest degree of hydration and structural refinement, confirming the superior influence of using magnetized water during both mixing and curing.

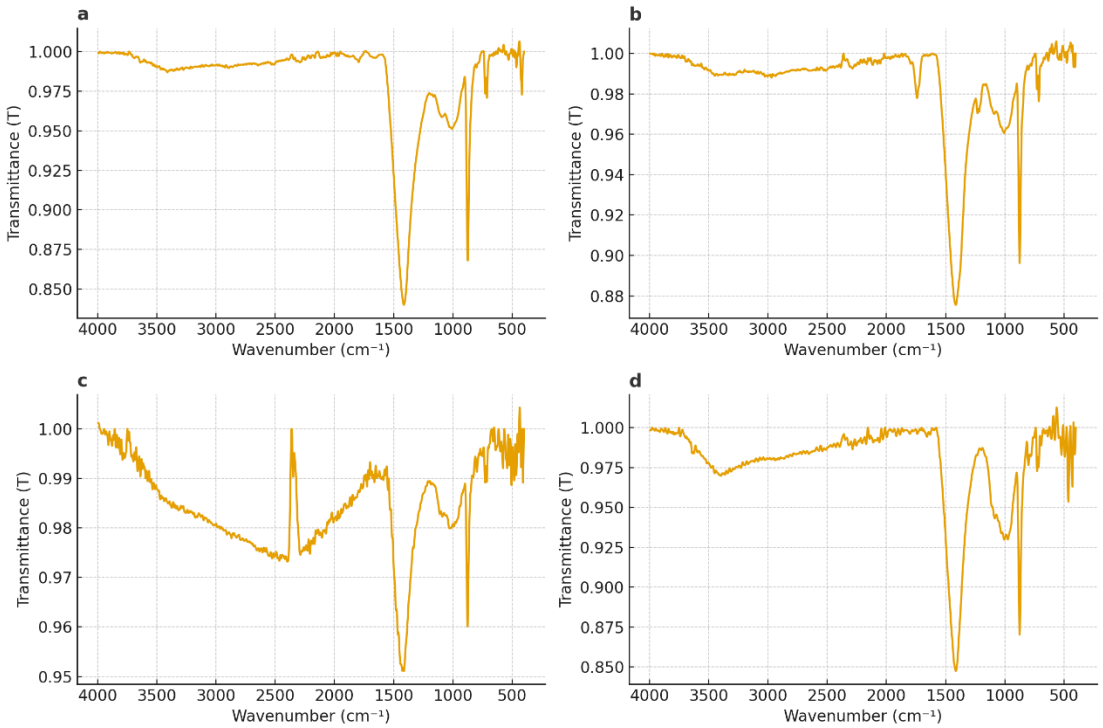

Figure 8. FTIR spectra of self-compacting concrete samples: (a) SCNTM (cured with magnetized water), (b) SCMTN (mixed with magnetized water), (c) SCNTN (control – normal water), and (d) SCMTM (mixed and cured with magnetized water).

The findings from XRD and FTIR analyses exhibit a strong correlation, confirming the effect of magnetized water (MW) on the hydration and microstructural evolution of self-compacting concrete (SCC). The XRD results showed higher portlandite and calcite contents in the SCMTM mix, indicating enhanced hydration and secondary carbonation. Correspondingly, the FTIR spectra of the same mix displayed intense Si–O stretching bands and reduced carbonate absorptions, suggesting the formation of a denser C–S–H gel network. The agreement between both techniques demonstrates that MW promotes more complete cement hydration and the stabilization of crystalline and amorphous phases. This consistency between XRD and FTIR observations aligns with previous studies, which reported that magnetized water enhances ion mobility, accelerates dissolution of clinker phases, and promotes C–S–H gel formation [9,20,24,25]. The complementary use of these techniques provides a more comprehensive understanding of how MW improves both crystalline and molecular-scale structures in SCC, ultimately leading to improved mechanical strength and durability.

4. Challenges and Future Research

Although the findings of this study demonstrate clear improvements in the mechanical and microstructural performance of self-compacting concrete when using magnetized water, several considerations must be addressed before large-scale adoption. The magnetization process requires continuous circulation of water through a magnetic device, resulting in measurable energy consumption that may affect the cost-effectiveness of the technique in industrial applications. Additionally, the magnetic effect is not inherently permanent; previous research suggests that magnetization intensity may diminish over time depending on storage conditions and environmental exposure, which may necessitate periodic re-magnetization or controlled handling procedures. Another challenge is the absence of standardized guidelines or specifications regulating the use of magnetized water in concrete production, which limits the comparability of existing research and hinders practical implementation. Furthermore, the influence of magnetized water may vary with cement type, supplementary materials,

and mix proportions, indicating the need for broader experimental validation across different concrete systems.

In light of these challenges, further research is recommended to establish the practical viability of magnetized water in concrete technology. Comprehensive energy and economic assessments, such as life cycle analysis or techno-economic evaluation, are required to determine the feasibility of scaling the magnetization process. Moreover, studies focusing on long-term durability—such as resistance to carbonation, chloride penetration, sulfate attack, and freeze–thaw cycling—would provide deeper insight into service life performance. Future work should also examine the stability and retention period of the magnetic effect under various operational conditions and identify the optimal parameters for maintaining consistent magnetization. Advanced microstructural characterization techniques (e.g., SEM, TGA, NMR) are encouraged to better understand the hydration mechanisms influenced by magnetized water, particularly the development and arrangement of C–S–H gel. Finally, extending investigations to alternative concrete types, including high-performance concrete, fiber-reinforced systems, and mixes incorporating supplementary cementitious materials, would help determine the broader applicability and generalizability of magnetized water technology within sustainable concrete development.

5. Conclusion

The experimental results demonstrate the significant influence of magnetized water (MW) on both the mechanical and microstructural performance of self-compacting concrete (SCC). When MW was used during mixing, the compressive strength at 7 days increased by 22.9% compared with the control (from 31.4 to 38.6 MPa), indicating accelerated early hydration and enhanced C–S–H gel formation. By 28 days, the improvement was 4.4% (from 43.3 to 45.2 MPa), suggesting that the main contribution of magnetic mixing occurs at the early stages of hydration.

Using MW for curing produced a more pronounced long-term benefit. The 7-day compressive strength increased by 12.4% (from 31.4 to 35.3 MPa), while at 28 days it rose by 9.5% (from 43.3 to 47.4 MPa). This improvement reflects continuous hydration and reduced microcracking during the curing phase due to the higher ionic mobility and surface energy of MW.

The combined use of MW during both mixing and curing yielded the greatest enhancement, with compressive strength increases of 25.8% at 7 days (from 31.4 to 39.5 MPa) and 14.2% at 28 days (from 43.3 to 49.45 MPa). Microstructural analyses (XRD and FTIR) supported these findings, revealing stronger Si–O absorption bands, reduced carbonate peaks, and a denser hydration structure in the MW-treated mixes.

Overall, the results suggest that applying magnetized water in both stages synergistically enhances hydration kinetics and microstructural densification. This dual application not only improves strength and durability but also contributes to sustainability by reducing water and energy requirements during mixing and curing. Therefore, MW can be considered an efficient and environmentally friendly approach for producing high-performance SCC.

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