Research Article

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Concrete strength development by using magnetized water in normal and self-compacted concrete

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Abstract: The main objective of this work was to adopt an environmentally friendly technology with enhanced results. The technology of magnetic water (MW) treatment system can be used in concrete mixture production instead of potable water (PW) to improve both workability and strength. Two types of concrete were adopted: normal concreter production with two grades 25 and 35 MPa and the self-compacted concrete (SCC) with 35 MPa grade. The concrete mixes containing MW instead of PW results showed that, for 25 MPa grade, an improvement in a compressive strength of 15.1, 14.8, and 10.2% was achieved for 7, 28, and 90 days, respectively. For 35 MPa grade, an improvement of 13.6, 11.5, and 9.1% was achieved for 7, 28, and 90 days, respectively. The mixture of SCC showed the highest improvement up to 16.2, 15.8, and 12.4% for 7, 28, and 90 days, respectively. The effect of MW is significant for 7 days compared to 28 and 90 days. An increase in the water content to cementitious material presents the more efficiency of MW, while the combined effect of MW and superplasticizer in SCC showed the best improvement with less water content for 35 MPa grade.

Keywords: normal concrete, self-compacted concrete, magnetized water

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1 Introduction

SCC was first proposed by Okomorain in 1986 and the prototype of SCC was subsequently developed in 1988 at the University of Tokyo [1]. For the time being, SCC is commonly used in the concrete buildings' construction, to satisfy the workability requirement.

For concrete construction with complex shapes and/or congestion of rebar, SCC will be an ideal solution to avoid segregation without using vibrators. The concrete of this form is a flowable and can be surface finished with a very good structural efficiency [2,3].

SCC can solve several problems in the pouring concrete, like unskilled labors, congestion of rebar, and difficulties of using vibrators [4,5]. SCC can be adopted to decrease, effectively, the time schedule of construction [6]. The mechanical properties of SCC are more suitable with economical cost [7].

Most of the researchers devote their effort on developing concrete with a high strength and satisfying economy requirement. Magnetic water (MW) technique can be considered a modern technique to achieve the aforementioned requirements [8,9]. In addition, MW is used widely in various fields as a green technology [10].

The mechanical and chemical properties of concrete can be affected by the quality and potable water (PW) type used in concrete mixes [11]. When PW flows through a magnetic field device, the water is known as a magnetized water as shown in Figure 1 [12].

In concrete mixes (with lower porosity and higher density), magnetized water can be efficiently used to improve the concrete strength in addition to workability, as a recent technology, instead of normal water [13–15].

It is worthwhile to mention that the hydration rate of concrete with magnetized water increases as the viscosity–surface area increases by a magnetization process. This process changes the PW's properties as the water–structure is aligned in unidirection. In other words, the bond angle and the molecule sizes change by a magnetization process [16].

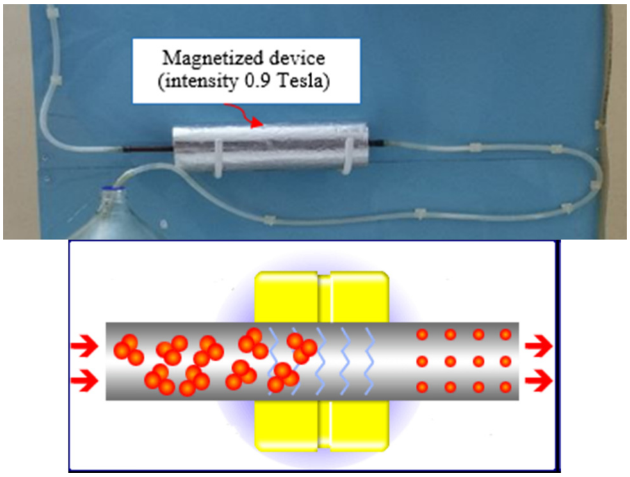

Figure 1: General arrangement of MW treatment apparatus.

By the action of hydrogen bond in water molecules will be broken and forms clusters, a molecule of water tends to be attracted to each other. Each cluster contains 100 water molecules [17]. The solubility can be increased as the magnetic field induction breaks down the water clusters and minimizes the bond angle [18]. As a result, the number of molecules in the clusters of water will be decreased from 13 to 5 (or 6) molecules. This will cause a reduction in the surface tension and the percentage of molecules will be raised as the strength will be increased subsequently by the hydration process [19,20].

The flowability of concrete can be improved by using magnetized water due to water circulation around the cement particles that are separated. These particles can be dispersed from each other and can lead to obviate the agglomeration of cement particles and can generate hydration layers surrounding them [1,21]. Furthermore, magnetized water may improve cement hydration and lower a penetration of more water molecules. This will help to squander the small clusters in a better way and can permeate much more easily through the exterior solid layer that covers cement particles. Therefore, hydration process will complete than with normal potable water (PW) [22].

The following paragraphs summarize the researchers' latest findings on the interpretation of MW behavior on the SCC properties.

Hameed *et al.* [23] reached to a conclusion that the use of colloidal nano-silica (CNS) can improve the grade of SCC compared to the ordinary mixture, with an average improvement of 41% (for 28 days). They studied the micro-silica (MS) effects (with a ratio of 10% as a reference) and CNS (2.5, 5, 7.5, and 10%) on the properties of both hardened in addition to fresh SCC.

Jouzdani and Reisi [24] showed that concrete workability can be increased and mechanical properties of SCC can be improved by using magnetized water. They observed that the use of MW in concrete mixture has considerable effects on the properties of fresh/hardened of SCC. The results showed that the concrete compressive strength was improved by 34.1%. In addition, the bending and tensile strengths were improved by a ratio of 52.4 and 74.2%, respectively. The study of Esfahani *et al.* [4] indicated that the use of MW in SCC can reduce the value of superplasticizer by 30%. The dosage can be kept stationary and the ratio of water to cement can be reduced by the effect of MW on SCC. The results showed that the amount of water required can be decreased by 10% and the concrete grade can be increased by 12% consequently.

The study of Gholhaki *et al.* [1] stated that MW and pozzolanic materials in SCC can improve the flowability and viscosity of SCC. They assessed physical properties of SCC incorporating MW in addition to several additives (silica fume, metakaolin, rice husk, and fly ash) (10 and 20% by weight of cement). The results showed that compressive and tensile strengths can be increased up to 49 and 41%, respectively, when SCC mixture contains MW and a 20% of silica fume. This mixture can be optimized the design of concrete mixture at the age of 28 days where the water absorption decreased up to 55%. In addition, the value of high-range-water reducer can be reduced for SCC, up to 45%, by using MW.

Karthik *et al.* [8] concluded that the SCC using sulfate-resisting cement prepared with MW can achieve an acceptable workability with a higher compressive strength (by 10%), a higher tensile strength (by 5%), and lower cost (6.74%) than the SCC designed with normal PW.

Ibrahim and Abbas [25] proved that the use of MW can be considered a successful technology to improve several mechanical properties (*e.g.*, compressive, flexural, and splitting tensile strength).

Khreef and Abbas [26] investigated the effect of using MW in reactive powder concrete (RPC) under different curing approaches. They stated that the grade in addition to flexural/splitting tensile strength for RPCs cured with several curing techniques can be improved by using MW. The results showed that the compressive strength for RPC mixes containing MW can be enhanced up to 7.66, 8.43, 8.86, and 9.15% for normal approach, autogenous method, warm-water technique, and curing at high temperature, respectively, at 28 days. Moreover, the compressive strength can be improved up to 34.4, 30.6, and 28.52% at 7, 28, and 90 days, respectively, with curing at high temperature method. On the other hand, Karkush *et al.* [27] and AL-Ani *et al.* [28] reviewed the use of MW in different disciplines and they especially studied the influence of MW on the geotechnical properties of soft, expansive, and swelling soils.

Finally, the aim of this experimental work was to study the effect of MW in normal and SCC with different grades of strength and water content and the combination effect of MW and superplasticizer.

2 Program of experimental work

2.1 Properties of material

The ordinary Portland cement (OPC – R 42.5) was adopted. The properties of cement in this study were evaluated, and the results are listed in Tables 1 and 2. Table 3 demonstrates the grading of the fine aggregate (FA) and crushed cores aggregate (CA), while the other properties are listed in Table 4. Structuro 520 is a non-typical superplasticizer according to the manufacturer's datasheet and complies with [ASTM C494-15] types A and F. Table 5 presents the properties of the MS. All tests were carried out at the Building Research Center.

2.2 Preparation of magnetized water

The properties of PW, which is in accordance with IQS 1703/2000, are listed in Table 6. It was used in all mixes as a reference. Figure 2 presents the transformation of tap water to magnetized water using magnetized water cycle

Table 1: Cement chemical properties

	Oxide composition (%)								Main compounds of cement			
	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	L.O.I	I.R.	C_3S	C_2S	C_3A	C_4AF
Results-OPC	63.02	19.97	6.05	3.18	2.19	1.89	2.69	0.4	53.27	17.14	10.65	9.66
IQS No. 5–19	—	—	—	—	≤2.8	≤5.0	≤4.0	≤1.50	—	—	—	—
ASTM C150-17	—	—	—	—	≤3.0	≤6.0	≤3.0	≤0.75	—	—	—	—

Table 2: Physical properties of OPC

	Specific surface/(Blaine) (m^2/kg)	Soundness/autoclave method (%)	Setting time (Vicat's method) (min)		Grade (MPa)			
			Initial	Final	2 days	3 days	7 days	28 days
Results	393.5	0.02	130	215	21	21.5	27	43.5
IQS No. 5–19	≥280	≤0.8	≥45	≤600	≥20	—	—	≥42.5
ASTM C150-17	≥260	—	≥45	≤375	—	≥12	≥19	

Table 3: Sieve analysis of FA and CA

	Sieve size (mm)								
	20	14	10	4.75	2.36	1.18	0.6	0.3	0.15
Cumulative passing-FA (%)	—	—	100	92	85	62	42	18	5
IQS No. 45-FA zone (2)	—	—	100	90–100	75–100	55–90	35–59	8–30	0–10
Cumulative passing-CA (%)	100	92	55	2	—	—	—	—	—
IQS No. 45-CA (5–14)	100	90–100	50–85	0–10	—	—	—	—	—

Table 4: Properties of FA and CA

	Specific gravity	SO_3 (%)	Absorption (%)	Material finer than sieve 75 µm (%)
Results-FA	2.6	0.28	0.85	3.6
IQS No. 45-FA	—	≤0.5	—	≤5
Results-CA	2.62	0.02	0.25	1.5
IQS No. 45-CA	—	≤0.1	—	≤3.0

Table 5: Properties of MS

	Oxide composition – abbreviation (%)							Physical properties			
	CaO	SiO_2	Al_2O_3	Fe_2O_3	SO_3	MgO	L.O.I.	Strength activity index (%)	Specific gravity	Moisture (%)	Surface-Blaine method (cm^2/g)
Results	0.69	93.47	2.15	0.65	Nil	0.69	2.14	125	2.2	0.66	20,000
ASTM C1240-15	—	≥85	—	—	—	—	≤6	≥105	—	≤3	≥15,000

Table 6: Water properties

	Cl^- (mgm/L)	SO_4^{2-} (ppm)	$CaCO_3 + HCO_3^-$ (ppm)	Inorganic impurities (ppm)
Results	99	784	144	2,050
IQS No. 1703/2000	≤500	≤1,000	≤1,000	≤3,000

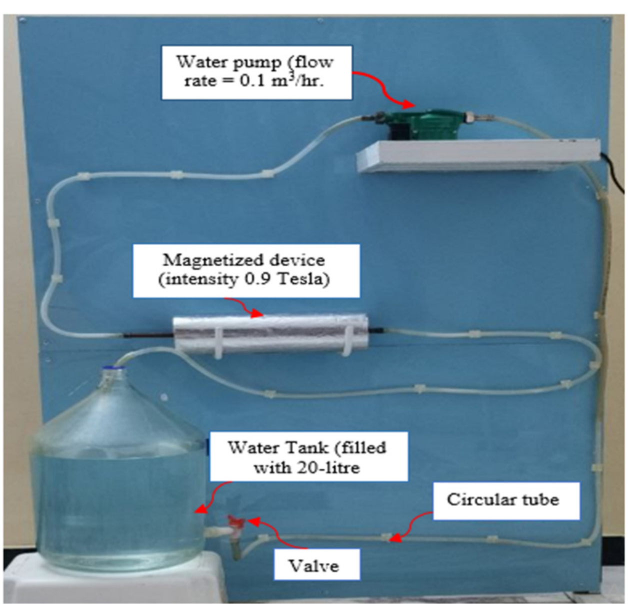

Figure 2: Magnetized water cycle developed in this study.

recommended by Al-Hubbubi and Abbas [13], Khreef and Abbas [14], and Ibrahim [15]. The adopted circulation time was 60 min to prepare 20 L in order to be used in different mixes. After preparing the magnetized water, it is used in all concrete mix for comparing and recognizing the efficiency of using.

2.3 Mixture proportion and preparation of specimens

Adopting the ACI 211.1 [29] strategy to prepare a normal mix of concrete with a specified cylinder grade of 25 and 35 MPa (31.25 MPa and 43.75 for cube, respectively) (at 28 days with a slump range of 7.5–10 cm using PW or magnetized water in mixing). The ACI 237R-07 code [31] that has been adopted affords a guideline for designing an SCC mix after many trials to approach 35 MPa (43.75 MPa for cube) and adjusts to preserve the standard SCC limits for fresh/hardened properties. All SCC mix proportions are presented in Table 7.

Table 7: SCC mix proportion

Mix No	Description	Cement (kg/m³)	FA (kg/m³)	CA (kg/m³)	Water (kg/m³)	≈W/C
N-T25 N-M25	Normal concrete specified compressive strength = 25 MPa	350	762	1,000	214	0.61
N-T35 N-M35	Normal concrete specified compressive strength = 35 MPa	450	624	1,000	214	0.47
SCC-T35 SCC-M35	Self-compacted specified compressive strength = 35 MPa	400 + 50 (MS)[1]	800	850	200	0.44[2]

[1]Addition of 1.2 SP (l/100 kg cementitious), [2]W/cm.

Mixing, production, and curing of normal concrete in the laboratory were done in accordance to the ASTM C 192 [30]. The mixing procedure is a substantial guide to gain the workability (filling, passing, and resistance to segregation) and the ACI 237R-07 [31] was adopted for mixing, and then casting in the different mold shapes according to test. Finally, all specimens were cured after 24 h in order to be tested at different ages [30].

2.4 Test methods

2.4.1 Fresh-concrete properties

The fresh properties for normal concrete checked by slump test according to the ASTM C 143 [32] were within the range of mix design requirements (7.5–10 cm). While the fresh properties for SCC requirements to cover the filling, flowing ability and resistance to segregation were directed by using slump flow and T50 cm, V Funnel, and L Box tests, according to EFNARC [33] as presented in Figure 3, which is within requirements.

2.4.2 Mechanical properties of hardened-concrete

Grade test for SCC was tested according to the BS EN 12390-3:2001 (*E*) using the hydraulic testing machine with a loading rate of 0.4 MPa/s. Cubes of a side dimension of 100 mm were tested at the age of 7, 28, and 90 days. Flexural strength test was achieved by using simply supported beam with third-point loading by using prism dimensions of 100 mm × 100 mm × 400 mm. The test was done according to the ASTM C78/C78M-16 with a loading rate of 1 MPa/min. The splitting tensile strength was done according to ASTM C496/C496M-11 with a loading rate equal to 1 MPa/min using cylinders' mold of 300 mm high and 150 mm diameter. Finally, air

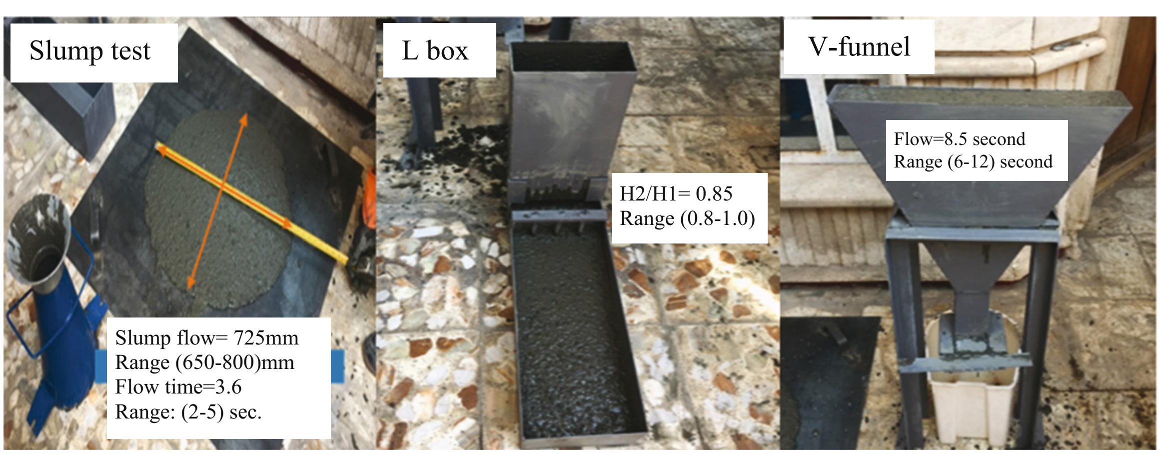

Figure 3: Fresh properties of SCC.

dry density test was made according to Iraqi guidelines No. 27.

3 Results and discussion

The results of strength for different concrete mixture at 7, 28, and 90 days and the dry density at 28 days are listed in Table 8. The results showed good improvements for all ages especially at 7 days that may be attributed to the mechanism of magnetized water and efficiency in concrete mix, since MW more effective charge at early ages [14,15].

Figures 4–6 present the improvement in compressive, tensile, and flexural strength when using magnetized water instead of PW. The results showed that, for a grade of 25 MPa, an improvement in a compressive strength of 15.1, 14.8, and 10.2% had been achieved for 7, 28, and 90 days, respectively. On the other hand, for a grade of 35 MPa, an improvement in a compressive strength of 13.6, 11.5, and 9.1% had been achieved for 7, 28, and 90 days, respectively. In other words, the results proved that increasing the water content to cement showed the effect of magnetized water.

The combined effect of superplasticizer with magnetized water showed higher improvement in the strength

Table 8: Concrete's mechanical properties (MPa)

Mixes	Description	Mechanical strength (MPa)	Age (days)		
			7	28	90
N-T25	Normal concrete grade = 25 MPa tap water	Compressive tensile flexural	24.38 2.715 3.209	32.50 3.135 3.706	35.75 3.289 3.886
N-M25	Normal concrete grade = 25 MPa magnetized water	Compressive tensile flexural	28.06 3.085 3.633	37.31 3.518 4.180	39.40 3.631 4.256
N-T35	Normal concrete grade = 35 MPa tap water	Compressive tensile flexural	33.83 3.199 3.780	45.10 3.694 4.365	49.61 3.874 4.578
N-M35	Normal concrete grade = 35 MPa magnetized water	Compressive tensile flexural	38.43 3.589 4.211	50.29 4.085 4.793	54.12 4.207 4.963
SCC-T	Self-compacted grade = 35 MPa tap water	Compressive tensile flexural	33.60 3.188 3.768	44.80 3.681 4.351	49.28 3.861 4.563
SCC-M	Self-compacted grade = 35 MPa magnetized water	Compressive tensile flexural	39.04 3.705 4.352	51.88 4.204 4.947	55.39 4.309 5.056

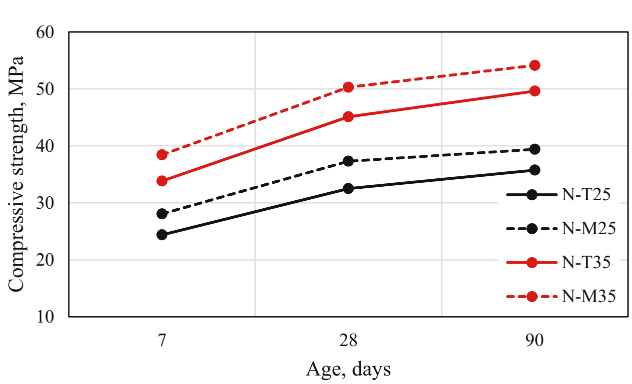

Figure 4: Compressive strength results for normal mixes using tap and magnetized water.

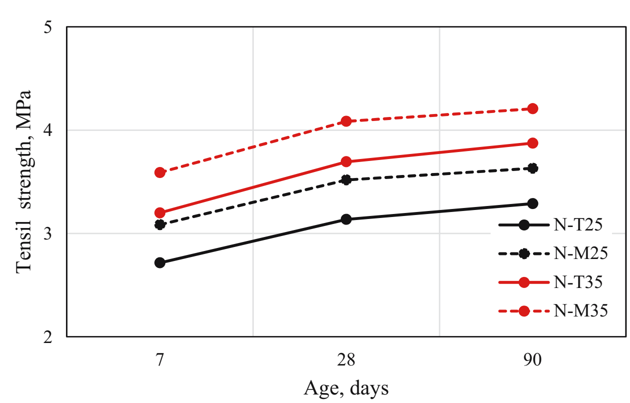

Figure 5: Tensile strength results for normal mixes using tap and magnetized water.

of SCC compared to the normal mix with approximately the same compressive strength despite the less water content. This may be attributed to the harmonious effect of them, since both of them trying to disperse other constituents led to improve the workability with more homogenous of concrete structure. The compressive, tensile, and flexural results are presented in Figures 7–9, respectively.

The percentage improvement of all concrete mixes containing magnetized water compared to tap water is presented in Figures 10–12 for compressive, tensile, and flexural strength.

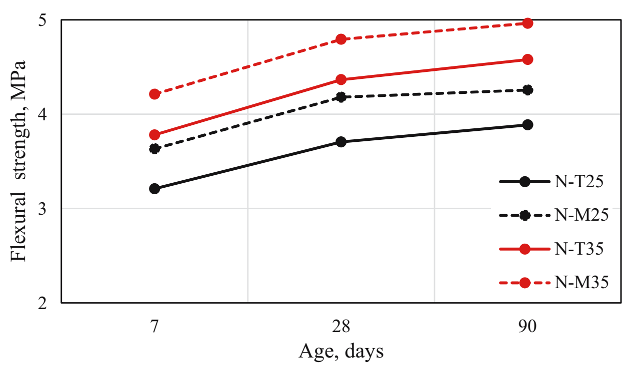

Figure 6: Flexural strength results for normal mixes using tap and magnetized water.

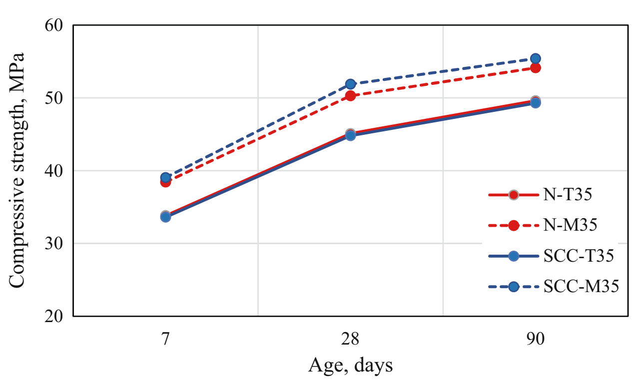

Figure 7: Compressive strength results for normal and SCC mixes using tap and magnetized water.

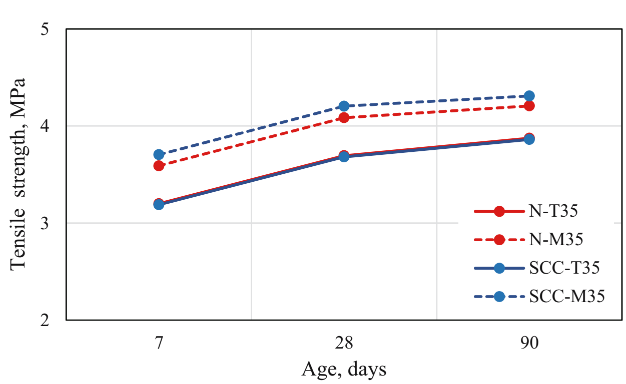

Figure 8: Tensile strength results for normal and SCC mixes using tap and magnetized water.

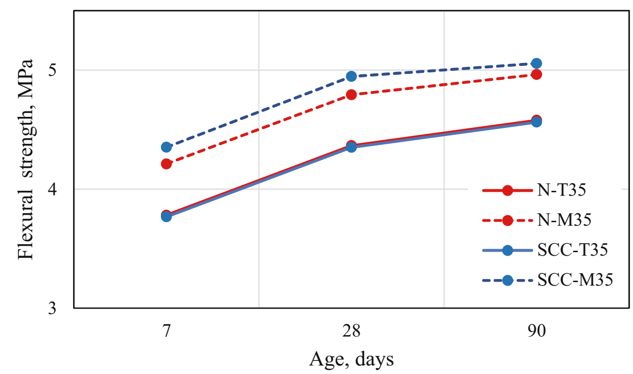

Figure 9: Flexural strength results for normal and SCC mixes using tap and magnetized water.

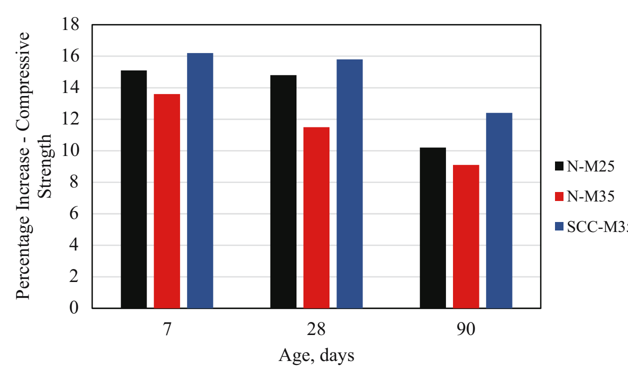

Figure 10: Compressive strength improvement using magnetized water instead of tap water for all mix.

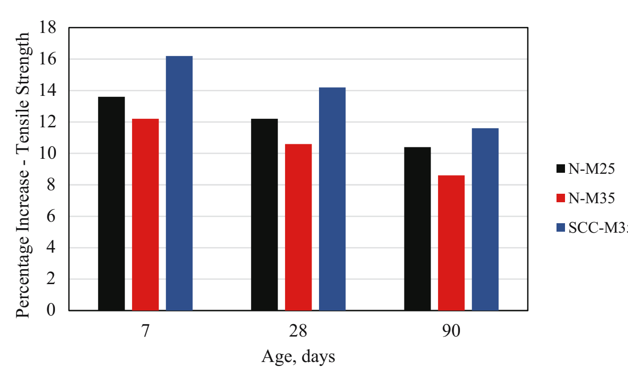

Figure 11: Tensile strength improvement using magnetized water instead of tap water for all mix.

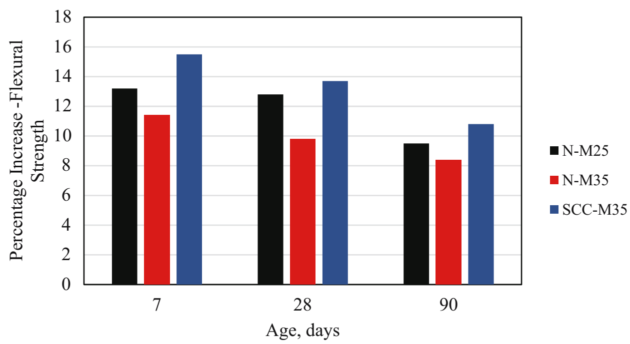

Figure 12: Flexural strength improvement using magnetized water instead of tap water for all mix.

4 Conclusions

1. The normal mix with 25 MPa specified compressive strength containing magnetized water showed an improvement in strength up to 15.1, 14.8, and 10.2% for compressive results and 13.6, 12.2, and 10.4% for tensile and up to 13.2, 12.8, and 9.5% for flexure at 7, 28, and 90 days, respectively.
2. The normal mix with 35 MPa specified compressive strength containing magnetized water showed an enhancement in the mechanical strength up to 13.6, 11.5, and 9.1% for compressive results and 12.2, 10.6, and 8.6% for tensile strength and up to 11.4, 9.8, and 8.4% for flexure at 7, 28, and 90 days, respectively.
3. The magnetized water effect is much more efficient with increasing water content to cement from 0.47 for grade 25 MPa to 0.61 for grade 35 MPa in the normal concrete mixture.
4. The combined effect of using the superplasticizer and magnetized water in SCC mixture more significant in strength up to 16.2, 15.8, and 12.4% for compressive, 16.2, 14.2, and 11.6% for tensile, and 15.5, 13.7, and 10.8% for flexural strength results.
5. Despite the water content to cementitious material is the smallest equal to 0.44 for SCC mixture compared to normal-concrete mix, the effect of magnetized water is much more significant.
6. Finally, for all concrete mix, the efficiency effect of magnetized water is clearer at early ages (7 days).

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