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Properties of Concrete with Magnetic Mixing Water

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Abstract. The effects of using magnetic water as mixing water in concrete on compressive strength, workability and required cement content was investigated. Concrete mixes were prepared using magnetic field treated mixing water and compared with regular concrete mixes that were made with normal (non-magnetized) tap water. Magnetizing the mixing water was performed by allowing the tap regular water to pass through magnetic fields that ranged in magnetic strength between 0.9 and 1.3 Tesla. Water / Cementitious material ratio, curing age, intensity of the magnetic field as well as cement content were used as the main variables that were investigated as to their influences on the behavior of magnetic mixing water concrete as compared to concrete with normal non-magnetized mixing water. Results showed that the workability of concrete has increased slightly compared with tap water mixed-concrete. At different curing ages, compressive strength of concrete was found to improve considerably as a result of mixing water magnetizing. The maximum enhancement of concrete compressive strength was obtained at the maximum magnetic field intensity used, which was 1.3 Tesla. Compressive strength enhancement was found to be more significant at early ages. It was also found that almost similar levels of fresh concrete workability and 28th day compressive strength and were obtained with 7.5% reduction of cement content for concrete samples made with magnetized mixing water as compared to those made with normal non-magnetized water. This cement requirement reduction may promote the potential to use magnetic mixing water as a positive modification towards a more sustainable concrete.

INTRODUCTION

BACKGROUND

Magnetic field treated water (MFTW) or simply called magnetized water is produced by allowing normal tap water to pass through a previously determined strength magnetic field. The use of magnetized water as concrete mixing water was investigated for the first time in Russia by Wulachoufuski and Alnanina [1]. It was then further investigated and developed in Japan, China and Europe. Research programs involved the use of magnetic field treated water as mixing water, curing water or both.

Available data indicated that magnetic water may enhance some fresh and hardened concrete properties, namely strength, workability, bleeding characteristic and resistance to freeze and thawing. [2-4]. Maintaining the same mechanical properties, MFTW can also be expected to reduce cementitious materials requirements. V Srinivasa Reddy reported significant compressive strength enhancement of more than 50% of the original strength as a result of exposing 20 MPa mix design cubes to magnetic water [5]. Depending on the water flow velocity and the time period of treatment, compressive strength enhancement in the range of 10-20% was obtained [6]. Highly differential increases in fresh concrete slump were reported by Abdel Majid et al. As high as 400% at w/c of 0.45 and as low as 25% at w/c of 0.55 slump increases as compared to concrete with normal non-magnetized mixing water [7]. In another research, the improvement was such slight that it has not exceeded 10% of the original slump [8].

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The mechanism by which magnetic water enhances fresh and hardened concrete properties can be explained in terms of changes in molecular structure of water. As a polar material, water consists of molecules with hydrogen bonding as the most predominant mechanism that is likely to attract these molecules to each other. That usually results in the formation of molecules collection which is called cluster forms. At the average room temperature, around 100 molecules of water generally gather with hydrogen bonding mechanism to form an averagely sized cluster. These groups of water molecules were found to be in thermodynamic equilibrium condition [9]. Within a magnetic field, these clusters are broken apart by the effective magnetic forces into single or smaller molecules. This transformation may efficiently improve the activity of water [10]. It seems reasonable to consider that the the penetration of smaller sized magnetic water molecules into the core part of cement particles during the hydration process of cement is easier and more effective. Cement hydration can hence proceed more efficiently, and that would be expected to improve concrete strength.

Being surrounded of similarly charged molecules of MFTW, cement particles tend to repulse from each other. The movement of mixture water is thus facilitated within the disperse cement clusters which means more portions within the cement particles will be reached by water that promotes the rate and degree of hydration. Furthermore, cement hydration usually results in the formation of a solid layer that covers cement particles, reducing further penetration of more water molecules. Magnetized water may improve this situation as it helps provide better disperse of small clusters, MFTW molecules can permeate more easily through the exterior layer, hydration is therefore more complete than with normal tap water.

A report on the use of Magnetic water for concrete mixing is available [11]. The MFTW can be stored in a reservoir for up to 12 hours, beyond that, its advantageous effects may be lost [1,11]. Some other authors reported that water usually does not pick up magnetism easily. It becomes magnetized only temporarily [1,4].

Cement manufacture is recognized as one of the most significant processes that cause serious impacts on the environment. Every metric ton of produced cement releases as high as 1 ton of carbon dioxide which represents a big environmental challenge facing concrete industry. Cement manufacture is known to contribute 7% of global CO2 emission. For more sustainable construction, it is therefore essential to minimize the use of cement in concrete. Concrete industry makes use of by-products like blast furnace slag, fly ash along with different types of nanoparticles as well as silica fume and other supplementary cementitious materials to partially replace cement in concrete mixtures [12-14].

The use of magnetized water may play a positive role in reducing cement requirements in concrete mixes, and hence contributing for more sustainable concrete structures and producing more echo-friendly construction material. By the molecular modification described above, magnetizing the mixing water is expected to result in better dispersion of water and cement phases, which may lead to improved strength and workability characteristics, or may be expected to lower water and cement quantities required to secure the same strength and workability levels. MFTW was reported to reduce cementitious materials requirements by 11% [15] and by up to 25% of cement content [6].

OBJECTIVES OF THE EXPERIMENTAL WORK

From the previous review, high variations can be noticed as regards the effects of using magnetic water on concrete compressive strength fresh concrete workability. The exact effect of using magnetic water on cement content requirements is not also fully agreed upon, both as a trend and extent. To find out the possible potential of using magnetized mixing water to obtain cement content requirement reduction in concrete mixes, it is first important to ensure obtaining enhancement of compressive strength and workability as a result of using magnetic mixing water with the regular cement content according to the mix design. The main objectives of this study may then be summarized by the followings:

1. Investigating experimentally the influence of magnetized mixing water on concrete compressive strength.
2. Investigating experimentally the influence of using magnetized water in the fresh concrete mixture on its workability expressed by concrete slump.
3. Determining experimentally if it is possible to utilize magnetic mixing water to reduce cementitious content in concrete mix maintaining the same levels of compressive strength and workability.

EXPERIMENTAL PROGRAM

Material Properties

The same materials (cement, fine and coarse aggregate and magnetic mixing water) were used for all specimens throughout this investigation and they are detailed below.

Cement

Type I OP Cement taken from Karblaa Cement Factory, which is complying with Iraqi Standard No. 5/1984 was used throughout this investigation. Table (1) shows the list of chemical composition and Table (2) shows the physical properties of the cement used.

TABLE 1. Percentages of oxides and chemical properties of the cement with specification limits.

Test name	% in the Sample	IQS NO.5/limit
CaO	55.12	-----
SiO2	22.45	-----
Al2O3	4.12	-----
Fe2O3	4.98	-----
Lime saturation factor	0.75	1.02-0.66
MgO	3.38	≤ 5.0 %
SO3	2.12	≤ 2.5 %
Loss on ignition	3.75	≤ 4.0 %
Insoluble residue	1.09	≤ 1.5 %
C3A	2.5	≤ 3.5 %

TABLE 2. Physical Properties With Specification Limits of the Cement.

Test name	% in the Sample	IQS NO.5/limit
Setting time-Initial (minute)	101	≥ 45
Setting time-Final (hour)	3 hours and 55 minute	≤ 10
3 day Compressive strength (MPa)	16.8	≥ 15
7 day Compressive strength (MPa)	24.5	≥ 23

Fine Aggregate (Sand)

Natural sand brought from Graiba region was used as a fine aggregate in this research. The sieve analysis test was conducted according to IQS 45/84. Table (3) shows the sieve analysis that conform with zone 3 of the Iraqi Standard allowable grading.

TABLE 3. Gradation of the Fine Aggregate.

Size (mm)	Passing %	IQS NO.45/1984 limit			
	Sample	Zone I	Zone II	Zone III	Zone IV
9.5	100	100	100	100	100
4.75	98	90-100	90-100	90-100	95-100
2.36	90	60-95	75-100	85-100	95-100
1.18	79	30-70	55-90	75-100	90-100
0.6	62	15-34	35-59	60-79	80-100
0.3	14	5-20	8-30	12-14	15-50
0.15	3	0-10	0-10	0-10	0-15
0.075	0	≤ 5.0 %	≤ 5.0 %	≤ 5.0 %	≤ 5.0 %

Coarse Aggregate

Natural crushed coarse aggregate from Badra area was used, with maximum sizes of 19 mm. The gradation is in compliance with the Iraqi standard specification No.45 (1984) as shown in Table (4), which also shows the percentage of SO_3 of the coarse aggregate along with acceptable limits according to the specification.

TABLE 4. Sieve Analysis and Sulfate Content of the Coarse Aggregate Used (With the Specified Limits).

Sieve size (mm)	Passing %	IQS NO.45(1984) limit
37.5	100	100
20	98	95-100
10	40	30-60
4.75	0	010
0.075	0	≤ 3 %
SO3	0.081	≤ 0.1%

Magnetic Water

Magnetized mixing water was produced by allowing ordinary tap water to move normal through a magnetic field that has been generated by means of electromagnets. Water has been treated by rotation within the predetermined intensity electromagnetic field for an average period of 3 minutes per 1 liter of water. The used strength values of magnetic field were (0.9, 1.1and 1.3 Tesla).

Concrete Mixes

In this study, three main types of mixes were used, the proportion of each mix ingredient was determined according to the criterion suggested byACI-211 mix design procedure. The mixes were designed to obtain cylinder's 28th compressive strength of 20 MPa, 25 MPa and 30MPa. Three more mixes were also used. These are derived from Mix C30 with reducing both cement and water contents by 5%, 7.5% and 10% to obtain mixes C30-5C, C30-7.5C and C30-10C respectively. Ingredients weights per cubic meter of fresh concrete are given in table (5).

TABLE 5. Details of Concrete Mix Design.

Materials weight (Kg/m3)	C20	C25	C30	C30-5C	C30-7.5C	C30-10C
Water	198	190	190	180	176	171
Cement	320	345	400	380	370	360
Fine Aggregate	1100	1065	1030	1030	1030	1030
Coarse	735	751	732	732	732	732
Aggregate	0.62	0.55	0.48	0.48	0.48	0.48
W/Cm						

Tested Specimens

In order to conduct the research program, 15 groups of cube specimens were cast as given in Table (6). For example C20-1.3 is the mix which has been designed according to ACI-211 mix design procedure for 20 MPa cylinder's 28th day compressive strength, and that has been exposed to 1.3 Tesla magnetic field strength. C30-10C-1.3 is the mix which has been designed for 30 MPa cylinder's 28th day compressive strength and with 10% reduction of each of cement and water contents, and that has been exposed to 1.3 Tesla magnetic field strength. From each mix, samples were tested to determine their compressive strength at different ages (3,7,14,21 and 28 days). Slump test was performed for each mix type immediately after mixing has completed.

TABLE 6. Details of Test Specimens Groups.

Specimen Group	Magnetic Field (Tesla)	W/Cm
C20-0.0	0.0	0.62
C20-0.9	0.9	0.62
C20-1.1	1.1	0.62
C20-1.3	1.3	0.62
C25-0.0	0.0	0.55
C25-0.9	0.9	0.55
C25-1.1	1.1	0.55
C25-1.3	1.3	0.55
C30-0.0	0.0	0.48
C30-0.9	0.9	0.48
C30-1.1	1.1	0.48
C30-1.3	1.3	0.48
C30-5C-1.3	1.3	0.48
C30-7.5C-1.3	1.3	0.48
C30-10C-1.3	1.3	0.48

RESULTS AND DISCUSSION

Effect of magnetized mixing water on fresh concrete workability

Workability of concrete is an important fresh concrete characteristic that plays a significant role in achieving in-situ concrete works. It is a main property that determines the mix ability to consolidate, fill the required volume with as little voids as possible with minimum segregation and bleeding. In this investigation, the workability is measured as fresh concrete standard slump that is tested right after mixing completion. As stated earlier, Slump test was carried out for each mix group mentioned in Table (5). The test results of fresh concrete workability as shown in Fig. (1) indicate that magnetizing the mixing water with 0.9 T magnetic field strength results in a slight increase in slump of C30 mixes, while no change was observed with C20 and C25 mixes. 1.1 T and 1.3 T magnetic water caused slight increases in slump of all the three mix types. These results are in consistence with the findings of B. Siva Reddy et al [8] who reported slump values of magnetized water concrete ranging between the same as to slightly higher than those of normal non-magnetized mixing water.

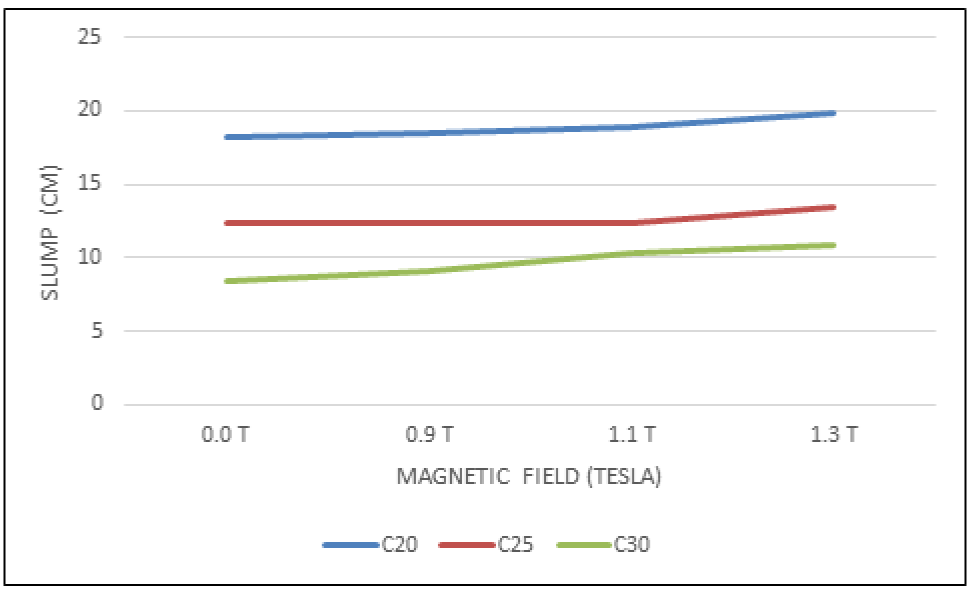

FIGURE 1. Concrete workability as affected by strength of magnetic field for different mixes.

Effect of magnetic mixing water on compressive strength of concrete

Average compressive strength at all values for the three different magnetic water strength (0.9 T, 1.1 T, 1.3 T) are presented in Tables 7,8 and 9 that concern mix types C20, C25, and C30 respectively. Data of these tables are also shown in Fig. 2,3 and 4 respectively. Throughout the whole tested range (0.0 to 1.3) Tesla, increasing the magnetic field strength is observed to increase concrete compressive strength at all covered mix types and curing ages. However, the enhancement is greater when the compressive strength is higher, with maximum influence observed at mix type (C30), that reached 17% strength increase with 1.3% T. These results are in consistent with those reported by S. Ahmed [8] who obtained 10-20% compressive strength increase with 1.2 T magnetic mixing water.

TABLE 7. Effect of Magnetic Field on Compressive Strength of Concrete Type C20.

Magnetic Field	Compressive Strength (MPa)				
	3 days	**7 days**	**14 days**	**21 days**	**28 days**
0.0 T	9.4	13.8	16.9	18.1	22.3
0.9 T	9.4	14.1	17.7	18.1	22.9
1.1 T	9.6	15.0	18.3	18.1	24.1
1.3 T	9.6	15.7	18.8	19.3	24.7

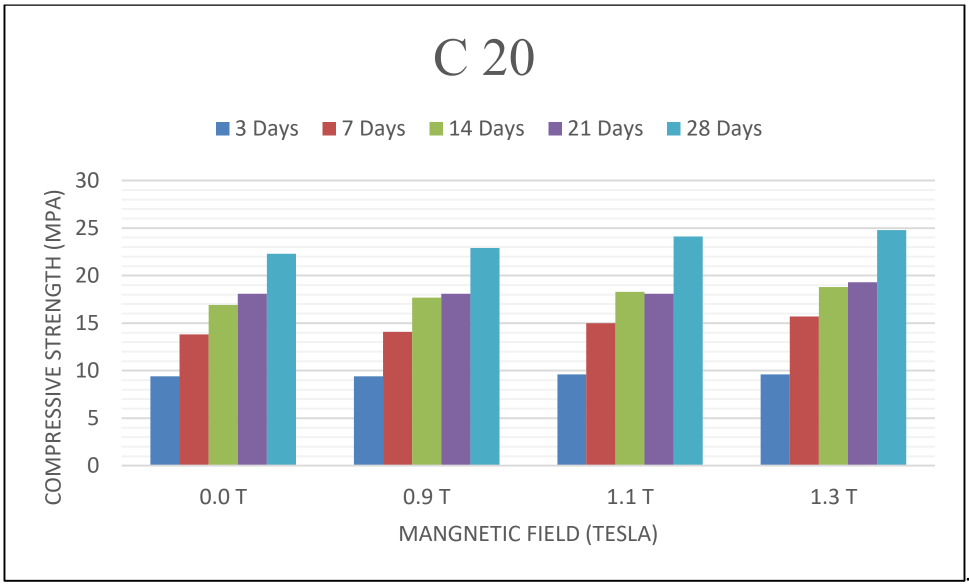

FIGURE 2. Influence of Magnetic Field Strength on Compressive Strength (C20).

TABLE 8. Effect of Magnetic Field on Compressive Strength of Concrete Type C25.

Magnetic Field	Compressive Strength (MPa)				
	3 days	**7 days**	**14 days**	**21 days**	**28 days**
0.0 T	14.0	20.1	22.9	26.1	29.1
0.9 T	14.8	20.3	23.6	26.3	29.8
1.1 T	15.3	22.8	23.8	28.5	30.8
1.3 T	15.3	23.1	25.3	29.3	32.7

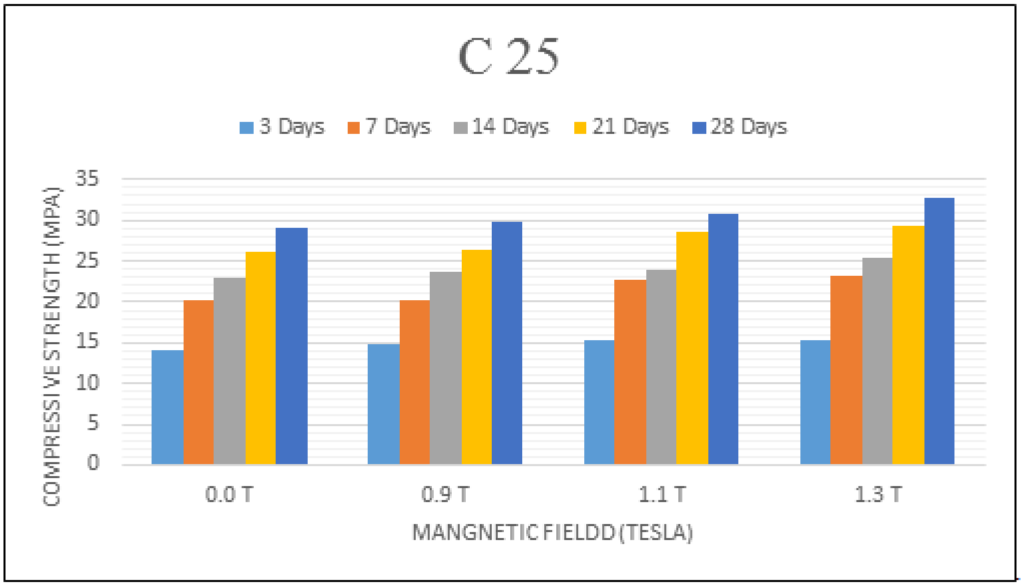

FIGURE 3. Effect of Magnetic Field on Compressive Strength (C25).

TABLE 9. Effect of Magnetic Field on Compressive Strength of Concrete Type C30.

Magnetic Field	Compressive Strength (MPa)				
	3 days	7 days	14 days	21 days	28 days
0.0 T	17.5	25.6	29.1	32.5	35.6
0.9 T	17.6	28.3	30.9	35.6	35.9
1.1 T	17.9	29.7	35.1	37	37.1
1.3 T	19.5	29.5	33.1	38.0	40.9

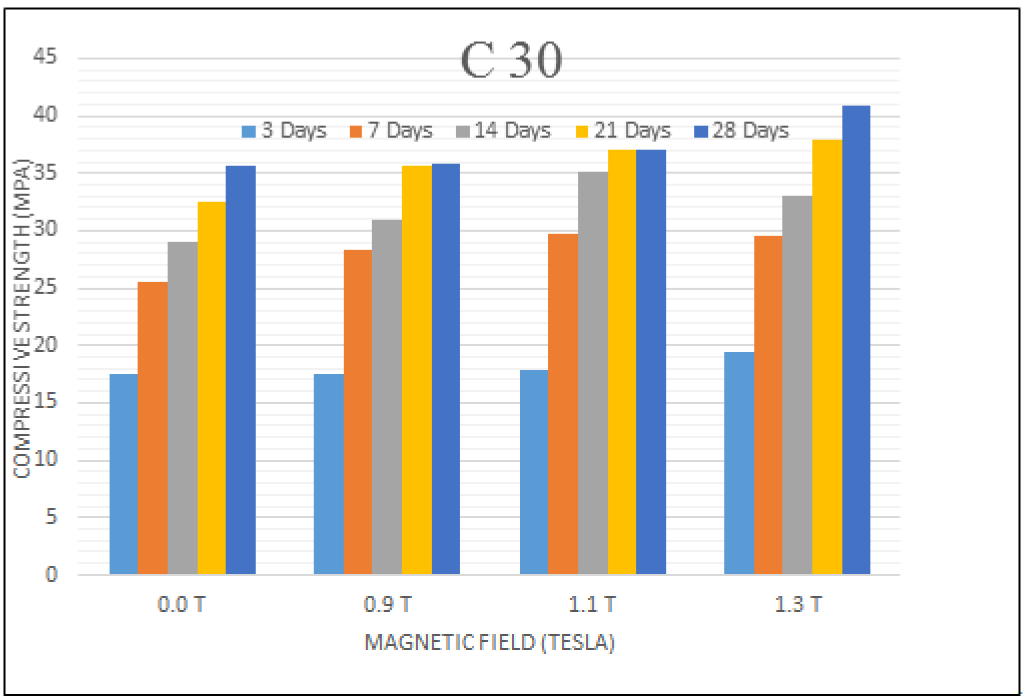

FIGURE 4. Effect of Magnetic Field on Compressive Strength (C30).

Effect of Magnetic Water on Cement Content Requirement

Investigating the possibility of achieving of considerable reduction in the cement content requirement of the concrete was an essential element in the program of this study, but could not be tried before obtaining positive results as regards compressive strength and to a lower extent, fresh concrete workability with the basic (no cement reduction) mixes. As the best results were obtained with C30-1.3 T specimen's group, the same C30 mix was modified to 3 more mixes that involved cement reductions of 5%, 7.5% and 10% from the original C30 mix. W/C ratio was maintained the same by making similar reductions of water contents.

Figure (5) shows the results of concrete workability. Slump shows very slight decrease with more reductions being made to cement contents, the least slump reading at 10% cement reduction is 85mm, which is still slightly higher than the slump of the original non-magnetized water, no cement reduction C30 mix .

Results of compressive strength test shown in Fig. (6) demonstrate that the 28 day compressive strength for 1.3T magnetized mixing water with 5% cement reduction is higher than that for normal tap water mix with no cement reduction. When the cement reduction increased to 7.5% the compressive strength is still slightly higher. However, the strength becomes lower than that of no reduction normal tap water mix. These results may suggest the potential to reduce the cement content in the mixture, provided that magnetic mixing water is used.

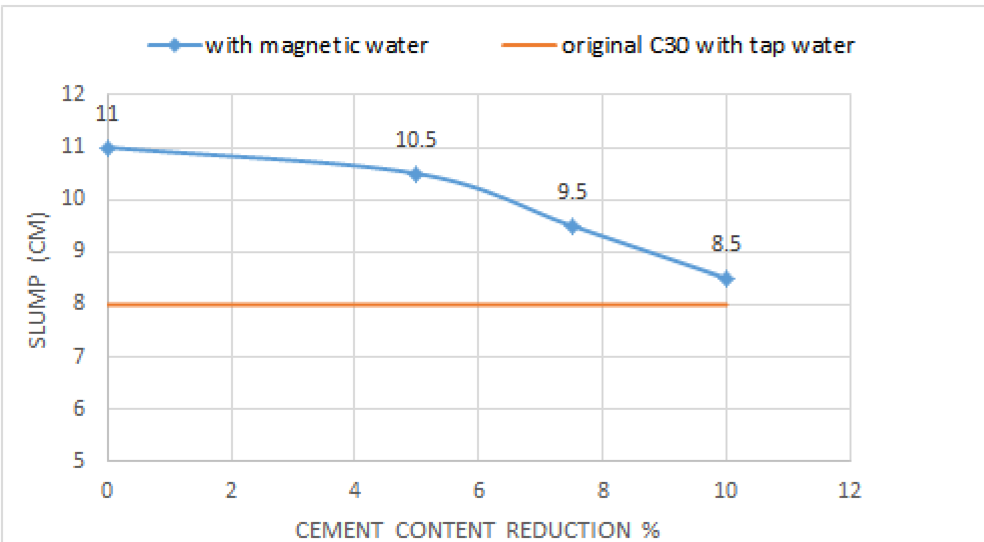

FIGURE 5. Relationship Between Slump and Cement Content Reduction of the Mix (C30) with Magnetic Field 1.3 T.

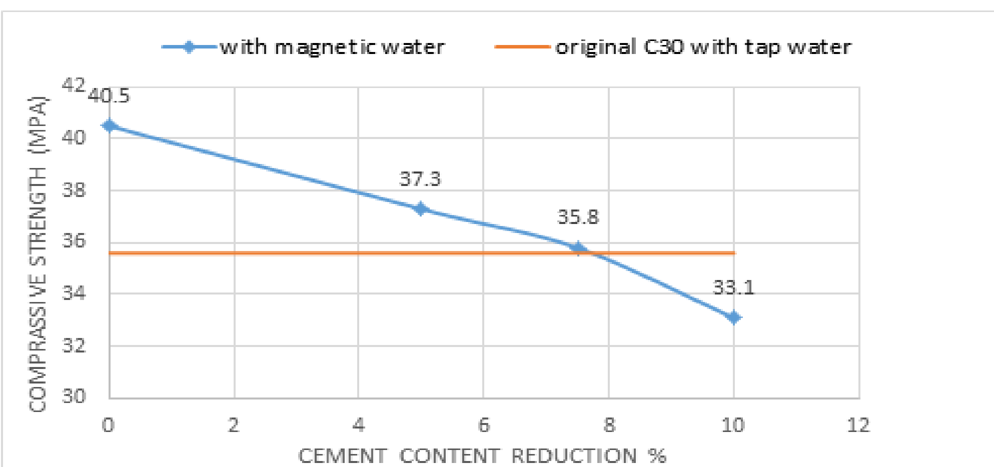

FIGURE 6. Relationship Between 28th day Compressive Strength and Cement Content Reduction of the Mix (C30) with Magnetic Field 1.3 T.

CONCLUSION

The following conclusions can be taken on the basis of the outcomes acquired in this study and important findings during the experimental work:

1- Magnetic water can be utilized as an efficient way to enhance concrete compressive strength when used as mixing water. Strength of the magnetic field is the most important key factor that determines the influence extent. When the magnetic field strength of water is 1.3 T, compressive strength of concrete samples increases by about 17%.

2- Magnetizing fresh concrete mixing water has resulted in slight improvement of its workability as compared to those concrete mixes that have been prepared with normal non-magnetized mixing water.

3- Maximum enhancement of concrete strength was obtained with C30 mix type at 1.3 T magnetic mixing water.

4- Using magnetic water, it may be possible to reduce cement requirements by as much as 7.5% maintaining similar levels of strength and fresh concrete workability. This may represent a promising potential to use magnetic mixing to improve the environmental performance of concrete.

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