Improvement Concrete Mechanical Properties Using Static Magnetic Field Treatment

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Abstract

In the current study, a new technology of magnetized concrete prepared using static magnetic field treatment is investigated. Methodology of the current proposal is to manipulate the placing process of the fresh concrete samples, while maintaining the same materials with the same configurations. The purpose of this study is to determine the effect of different magnetic treatments to the fresh and hard concrete characteristics. Five set of samples are planned, one set using traditional process without magnetic treatment, while the other four sets are treated with 0.04, 0.08, 0.12 and 0.15T (Tesla), respectively. The results showed that directly applying the magnetic field on concrete increases the compressive strength about (3-15%) and it simultaneously improves the flow capacity (workability) for the fresh concrete corresponding to some certain treatment ranges. Unlikely, the study showed that the magnetic treatments could be detrimental for some other range of treatments especially at long-term performance. The results of this study could be a first step towards devolving new generation of smart structures through application of magnetic field treatment to the fresh concrete.

***Keywords**:* **Magnetization of fresh concrete, Mechanical properties, Magnetic treatment, and workability.**

1. Introduction

With the advancement of technology and increased field application of concrete and mortars the strength, workability, durability and other characteristics of ordinary concrete are continually undergoing modifications to make concrete more suitable for any situation [1,2]. The usage of magnetized water while mixing concrete will increase compressive strength, also there will be a higher workability for the same water to cement ratio. Many researchers proved that the scale formation is greatly reduced if the water passes through an intense magnetic flux which in turn changes the physical structure of water molecules and softens the hard water. Ahmed, 2009, [1] conducted an experimental investigation to study the effects of using magnetic water on engineering properties of concrete. The study explains elaborately the method and the process of magnetic water production for different flow speeds through different magnetic strengths. The study became a guidelines for many researchers used to conduct qualitative studies with regard of magnetic treatments.
A number of researches have been conducted to improve concrete mechanical properties, of which the compressive strength is the most significant, through magnetic treatment of water [3, 4, 5]. Other researchers produced magnetized water using various techniques [6-10]. In general they concluded that, the uses of magnetized water can improve the workability and

increas the compressive strength by 10 to 25% and a greater increase in compressive strength is achieved when magnetic strength of treated water is 0.8 and 1.2 T.

Iman et al. 2017, [11] improved flexural capacity of reinforced concrete members, using alternating magnetic field and alternating current electricity of different intensities. The study showed that the structural properties such as load-bearing capacity, deflection, bending stiffness, and ductility during the loading history were affected corresponding to the different magnetic field treatments.

Recently Khamees et al. 2020, [12] investigated effects of using magnetic water in concrete on compressive strength, workability and required cement content and they discovered that the maximum enhancement of concrete compressive strength was obtained at the maximum magnetic field intensity used, which was 1.3T. With the increase of using magnetized water in concrete, it is essentially required to provide, a simple, easy and applicable way to make it readily available to be used in concrete casting process. Since, the way of producing magnetized water is normally sensitive for water flow speed and magnetic field density. Moreover, it is uncertain that magnetized water can be stored. Therefore, in the current study a new technology for magnetizing the fresh concrete using different magnetic flux density is investigated. Methodology of the current proposal is to introduce a "magnetic treatment unit" prior to pouring the fresh concrete. Five set of samples are planned one batch using traditional process without magnetic treatment, while the other four batches are treated with 0.04, 0.08, 0.12 and 0.15 T.

Almost all the experimental results have shown an increase in strength and workability of the concrete, the aim of this study is to quantify the optimal treatment level for fresh concrete to be recommended in concrete preparing process and specify the other negative consequences of the treatment to the fresh concrete.

2. Research Significance

Researchers are interested in the form of promoting concrete and concrete structures through product developments and improved efficiency. However, the effect of directly applying the magnetic field to fresh concrete on their properties have not yet been fully addressed (previous studies were focused on liquid treatments "magnetic water"). High magnetic flux density (> 0.08 Tesla) is often used. Hence, this paper reports on an experimental study that aims to give engineers more confidence in the use of magnetic field treatment (mix treatment) in concrete production.

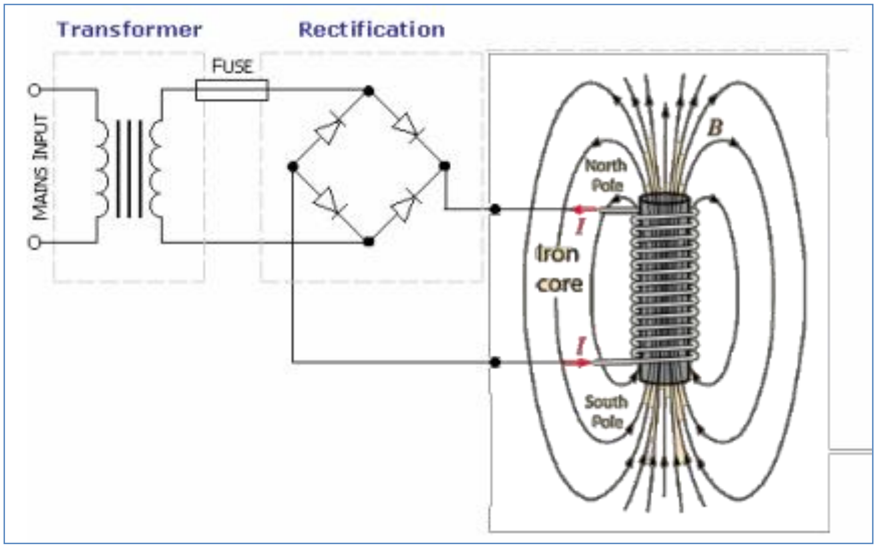
3. Principles of Magnetic Treatment for Fresh Concrete (MTFC)

When an electric current flows through a wire, a magnetic field is produced around the wire. The magnitude and direction of the field depends on the cross section of the wire, the direction and magnitude of the current through the wire. If the wire is wrapped into a loop, the field near the center of the loop is perpendicular to the plane of the loop. When a current flows in the solenoid coil, a magnetic field is produced, which is the result of Ampere‘s Law [13,14]. The right hand rule determines the direction of the magnetic field inside the pipe. The strength of the magnetic field is proportional to the product of the current, ‗**I**', and the number of turns of the coil in the unit length, ‗**n**' (**N/L**) as:

$$B=\mu_o \times n \times I \qquad \ldots(1)$$

Where: μ_o is the magnetic constant also known as vacuum permeability or permeability of free space, which is equal $4\pi \times 10^{-7}$ and its unit of Newton per square ampere ‗I^2'. The magnetic field force is also known as lines of magnetic flux or magnetic field lines. The unit

of flux density is taken as the density of a magnetic field or magnetic flux density ‗B‘ and the unit termed as ‗Tesla‘ or Weber per meter square, ‗Wb/m^2‘.
Magnetic field lines do not go randomly. Field lines are normally useful for visualizing vector fields. These are not physical, they are actually present at specific locations, and the direction is a convention. The field lines are taken to direct away from the North-pole and towards South -pole. Figure (1) shows the schematic diagram of the circuit used in the current study to generate the magnetic field, lines from North and South poles illustrate the static magnetic field that generated when the current 'I' flows in the coil.



Figuer (1): Used circuit to produce static magnetic field.

Figure (2) shows the developed magnetic field generator used in to treat the fresh concrete prior to placing in the molds. The device was developed in such a way to produce various magnetic flux intensities (B) due to the changes in the number of roles (N) and electric current (I), then calculate the magnetic flux from Eq.(1). In the current study the fresh concrete is treated in the device core (diameter 50 mm, length 300 mm).

There are three main factors that determine the magnetic properties of a material. The most basic factor is (i) the configuration of the electrons in the material's atoms; At the next level (ii) the ability of the atoms or molecules in the material to align magnetically (this is an important parameter that determines whether the material responds to a magnetic field); the final factor is (iii) the alignment of domains or sections in a solid object. The alignment is of high importance in the magnetic properties of materials, Liquids and gases. Basic fresh concrete components are typically non-magnetic materials because their molecules aren't held in place as they are in magnetic materials, as an exception the alignment of the ion charge can be affected at the surface of the particles, as shown in Figure (3). The positive and negative charges will be separated under the influence of a magnetic field; the molecules are aligned in accordance with the direction of the magnetic field. Figure (3) illustrates the resulting alignment at the surface of the fresh concrete components, the molecules are in an orderly arrangement, causing the particles to coagulate and aggregate In addition, the number of dipoles pointing in the direction of the field increases with increasing field strength.

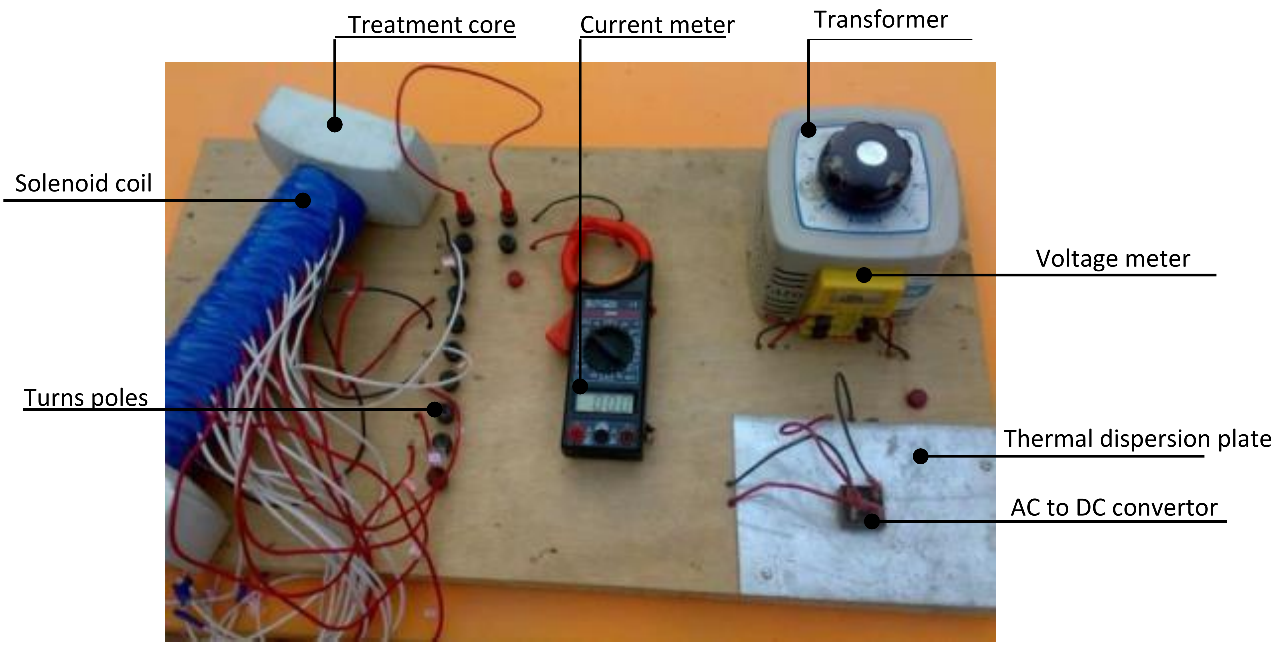


Figure (2): The magnetic field generator

This makes it more likely that the particles coagulate and that uncommon or unnecessary particles or pollutants can be removed. Hibben, 1973, [15] and Oshitani et al. 1999, [16] claimed that the effectiveness of a magnetic application ultimately depends not only on the magnetic strength but also on the magnetic gradient or magnetic flux concentration, which changes frequently along the magnetic device. Figure (4) shows two concrete particles, without and with magnetic treatment, the forces affecting the particle charge when magnetic field is applied in vertical direction. This force will separate the particle with positive solid and negative charge. The surface of the solid or liquid interface nucleus can be described as a surface characterized by a uniform charge density (Figure 4a). When an external vertical electric field is applied, the charge density is modified by a polarization effect, as shown in the schematic diagram in Figure (4b).

One of the best examples of magnetic applications is the Magnetic Resonance Imaging (MRI). (MRI) and it is used efficiently to examine the inside of the bodies with sufficient clarity. By applying static magnetic field to the human body which most contains water (more than 70%) makes the water molecules distributed throughout our body in different ways and the MRI machine is able to see these differences and capture an image for the body. In the current study, a quit similar principle was developed and used to apply the necessary magnetic treatment to the fresh concrete while passing the fresh concrete thought out the treatment core.

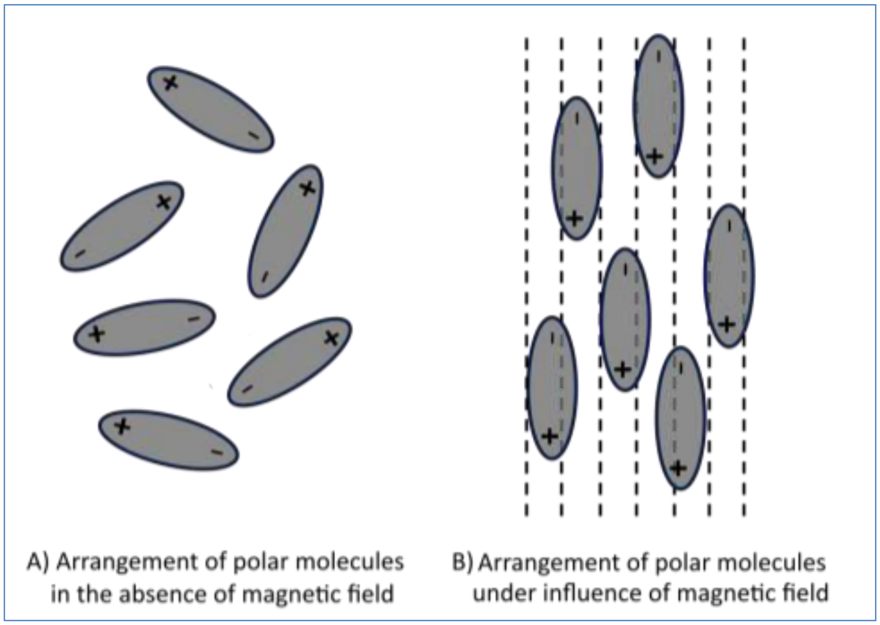


Figure (3): Molecules arrangement with and without magnetic field

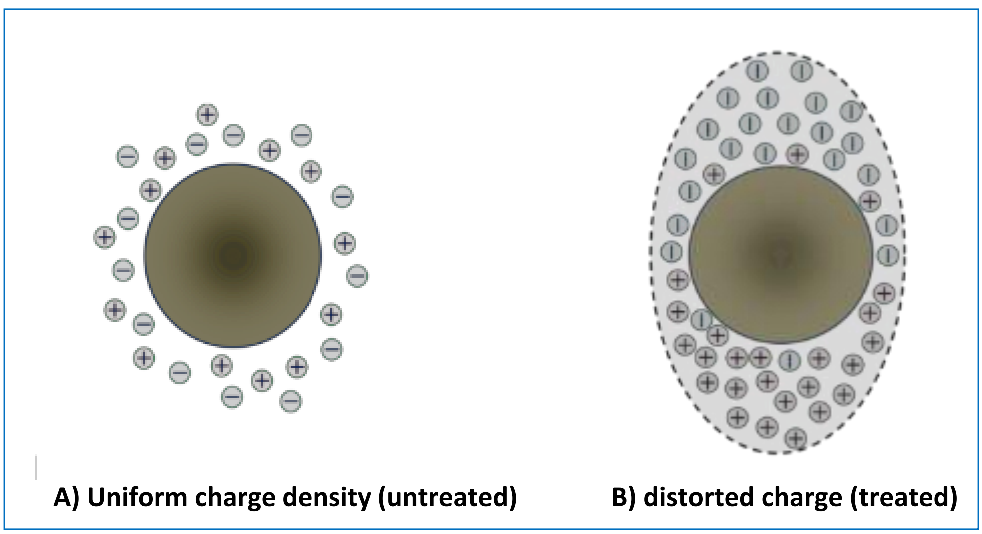


Figure (4): Ion charge particles (Beruto and Giordani, 1995)[17]

The MRI machine has a special coil of wire that is therefore the purposes of producing the needed magnetic energy to _irritate‘ the low energy hydrogen nuclei. The schematic diagram shows the basic components of the MRI machine, while passing the current 'I" magnetic field rapidly changing the diagram of water molecules in the body at the same time capturing X-ray images [18].

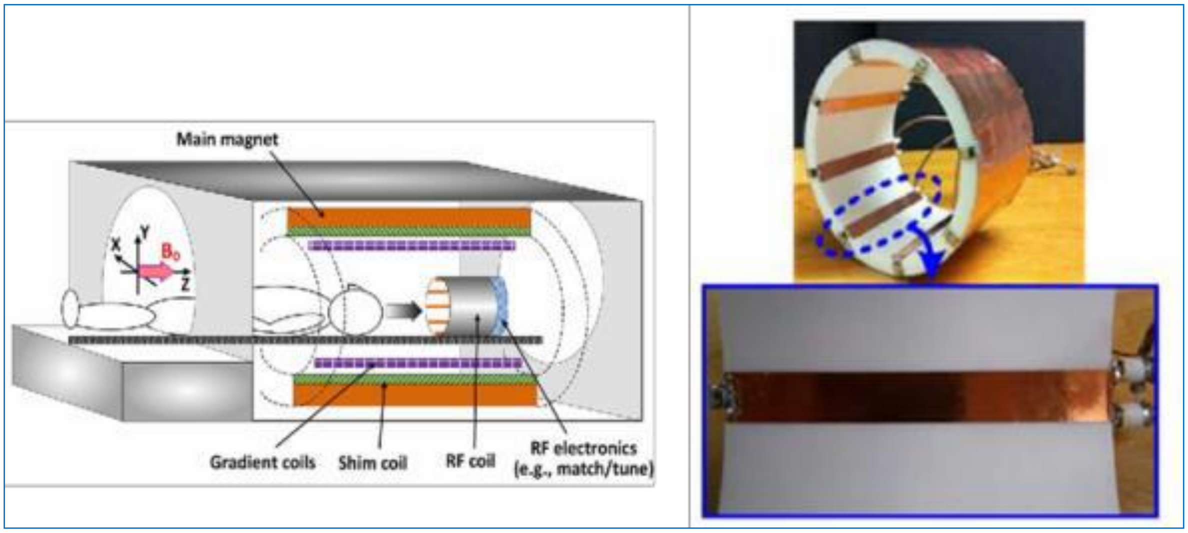


Figure (5): Structure illustration of a typical MRI scanner [18]

4 Experimental Investigation

Materials:

Ordinary Portland cement 'OPC' used in this research is according to ASTM specifications [19] with Grade 42.5. The chemical and physical properties of cement are provided in Tables (1) and (2), respectively [20-24].

Table (1): Chemical properties of Ordinary Portland Cement 'OPC'

LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O
3.87	21.7	4.8	3.08	60.2	2.85	2.43	0.62	0.45

The fine aggregate used in this research is river sand (uncrushed) and the maximum size of fine aggregate is 4.75 mm. Natural uncrushed gravel (local river gravel) is used as a coarse aggregate, It is well-graded and the maximum size is 20mm. Both of fine and coarse aggregate were grading within ASTM specifications. The physical properties of these aggregates are shown in Table (3) [25-31].

Mix proportion

In order to investigate the effect of different magnetic treatments on compressive strength and consistency of concrete, five batches are used, these batches are designated as N, MT1, MT2, MT3 and MT4; batch N is the untreated mix. While, batches MT1, MT2, MT3 and MT4 refers the concrete specimens which treated with constant magnetic intensities of 0.04, 0.08, 0.12 and 0.15T, respectively. All the specimens had similar mix proportion (1: 2.25: 1.85/0.36 by weight) and the total weight of materials are as listed in Table (4). All samples are tested at the age of 7- days and 28- days.

Table (2): Test method & specifications of OPC cement (42.5 Grade)

Component	Unit	Result	Standard
Bulk Density	kg/m^3	0441	ASTM C-188
Normal Consistency	%	24.00	ASTM C-187
Fineness	%	59.01	ASTM C-184
Initial Setting Time	Mints	90.11	ASTM C-191
Final Setting Time	Mints	001.11	ASTM C-191
Soundness	Mm	1.00	BS 196-3

Table (3): Physical properties of coarse and fine aggregate

Aggregates	**Component**	Unit	Result	Standard
Fine	Bulk Density	kg/m^3	1650	ASTM C-29
	Fineness Modulus	-	2.75	ASTM C-136
Coarse	Bulk Density	kg/m^3	0901	ASTM C-29
	Fineness modulus	--	3.2	ASTM C-136
	Water Absorption	%	0.0	ASTM C-127

Testing Of Specimens

To find the effect of magnetic field on workability and compressive strength of fresh and hardened concrete, the concrete specimen's cubes were tested using the following tests:

Slump test

Slump test was conducted to measure the consistency of fresh concrete, to identify the effect of direct applying of static magnetic field on fresh concrete workability, the test carried out according to BS 1881: part 102:1983 requirements [32].

Concrete Compressive strength:

Prediction of compressive strength of concrete is very important since it affects other concrete properties. In this study compression test of concrete was conducted using Universal Testing Machine _UTM' by applying direct compression load to the concrete cube

(100×100×100mm) samples to determine the compressive strength capacity following EN-12390-3:2001[33] requirements . The reported values represent the average results of three cube samples.

Table (4): Treatment levels to fresh concrete and mix proportions

Specimen		Magnetic flux intensity (T)	Water/Cement ratio	Cement (kg)	Sand (kg)	Gravel (kg)	Water (kg)	Target strength (N/mm^2)
Untreated	**N**	1.1	0.36	450	1010	830	160	40
Treated	MT1	0.04	0.36	450	1010	830	160	40
	MT2	0.08	0.36	450	1010	830	160	40
	MT3	0.12	0.36	450	1010	830	160	40
	MT4	0.15	0.36	450	1010	830	160	40

5. Results and Discussion

Effect of magnetic field treatment on Consistency of concrete

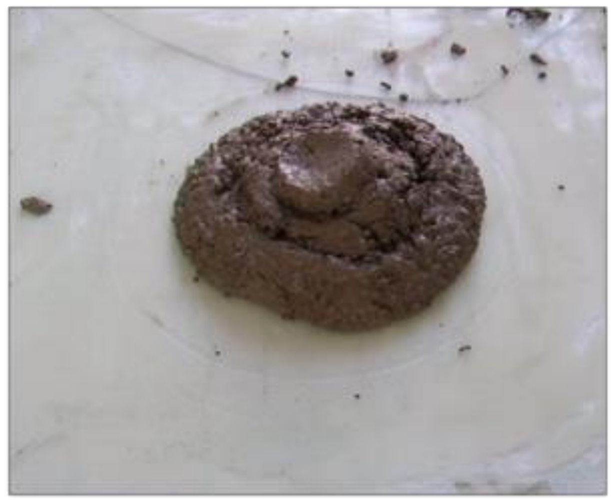
Experimental measurements for concrete workability for both treated and untreated mixes showed significant improvements in terms of horizontal and vertical slump magnitudes as presented in Table (5). In term of horizontal flow test, ratios of D_M 'average diameter of settled fresh treated concrete in flow table test' to D_N 'average diameter of settled fresh untreated concrete' were higher 74%, 81%, 78% and 59% corresponding to magnetic treatment intensity of 0.04, 0.08, 0.12 and 0.15T, respectively. Table (4) explains utilizing of magnetic field treatments improves vertical slumps of concrete as compared to normal concrete. The measured slump for untreated mix was 350mm, unlikely it was 70%- 91% higher in same mix after conducting magnetic treatment for fresh concrete. Furthermore, untreated batch did reach to a diameter of 500mm, while for treated mixes it was required a time of 8.1, 9.01, 5.74, and 10.4 second, respectively. Figure (6) compares the workability of treated and untreated mixes, the improvement in mix consistency due to magnetic treatment to the fresh concrete is quite clear.

The significant enhancement in fresh concrete consistency in treated mix was due surrounding the water partials all other mix components, and due to the presents of magnetic field which disperses cement partials from each other and generates hydration layers surrounding them, in addition to that magnetic field increases their molecular kinetic energy and with this increases the internal energy breaks and/or change some of the hydrogen bonds, resulting in more separate water molecules as shown in Figure (7).

Table (5): Effect of magnetic field treatment on Consistency of concrete

Specimen	Slump diameter (mm)	$D_{average}$ (mm)	D_M/D_N	*T500 (sec)	Vertical Slump, S (mm)	S_M/S_N
N	301-300	001	-	---	350	-
MT1	600-730	049	1.74	8.1	665	1.90
MT2	650-690	001	1.81	9.01	670	1.91
MT3	650-670	001	1.78	5.74	660	1.89
MT4	560-620	951	1.59	10.4	590	1.69

A) Treated fresh concrete (intensity 0.12T)



B) Untreated fresh concrete

Figure (6): Effect of magnetic fields on workability of concrete

Effect of magnetic field treatment on concrete strength

The results related to compressive strength showed that the compressive strength of specimens with magnetic field treatment were higher than that of the normal mix by 13%, 15%, 19% and 4% corresponding magnetic field intensity treatment to fresh concrete of 0.04, 0.08, 0.12 and 0.15T, respectively at 7 days age test as listed in Table (6). Unlikely, the magnetic treatment showed a lower strength increases at 28 days test and the relative increases in compressive strength for treated to untreated samples were higher in about 2%, 5% and 14% corresponding magnetic field intensity treatment to fresh concrete of 0.04, 0.08

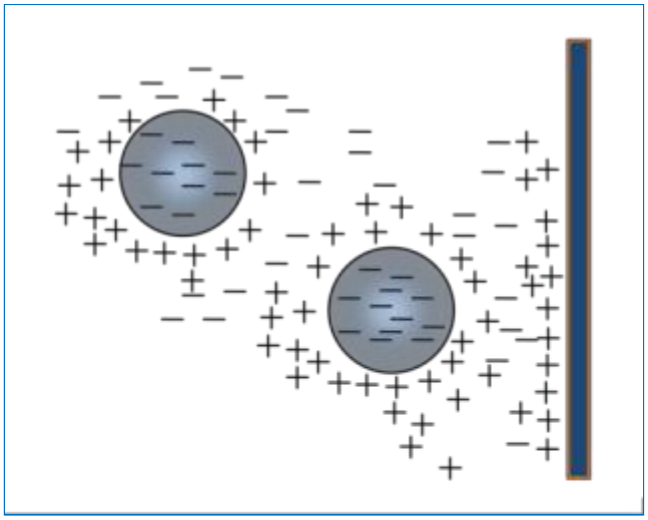


Figure (7): Enhanced surface charge on colloidal particles

and 0.12, respectively. While the MT4 'magnetic field intensity of 0.15T' showed 2% lower than untreated samples. Never the less, 7 days test showed also a marginal increase as compared to the other rang of treatment levels. Although the same mix proportions were used for all specimens, the increases in compressive strength were dominated on the flux density as shown in Figure (9). The magnetic flux intensity of 0.12T 'MT3' proved the best result in term of strength performance for both 7 and 28 days tests among the rest of intensity treatments.

Table (6): Effect of magnetic field treatment on compressive strength of concrete

Specimen	Compressive strength at 7 days (N/mm^2)	f_{cM}/f_{cN} at 7 days	Compressive strength at 28 days (N/mm^2)	f_{cM}/f_{cN} at 28 days
N	30.7	-	42.8	-
MT1	34.8	1.13	43.8	1.02
MT2	35.2	1.15	45.1	1.05
MT3	36.4	1.19	48.9	1.14
MT4	31.9	1.04	41.8	0.98

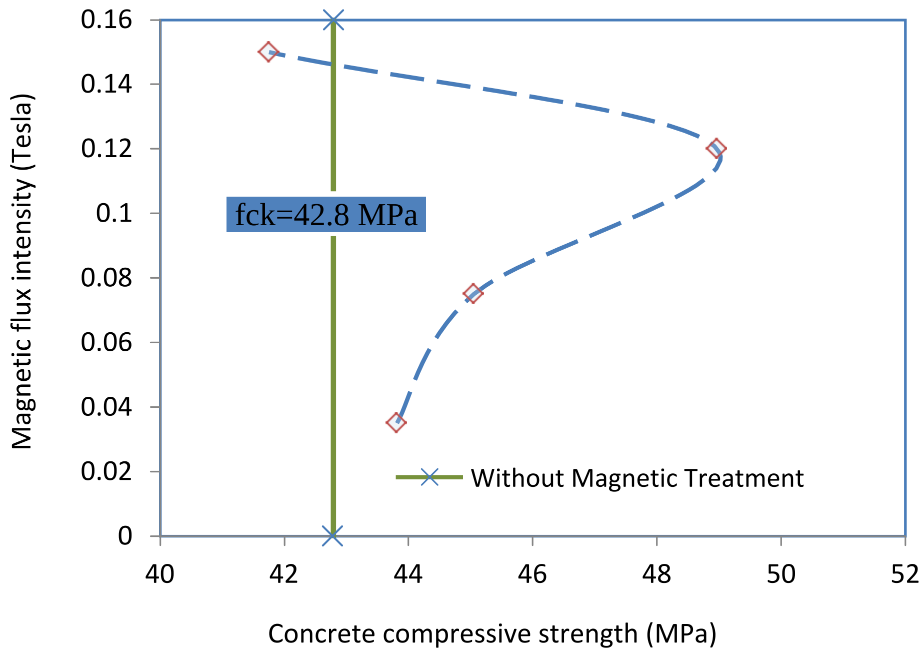
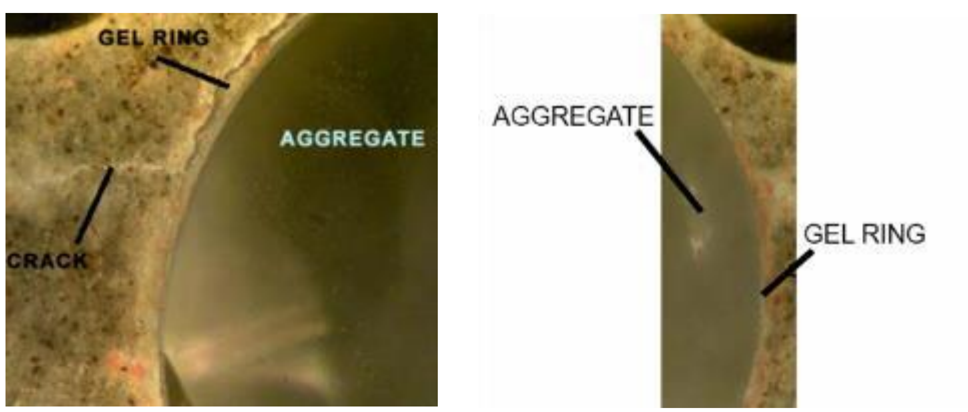


Figure (8): Behavior of concrete strength vs. various magnetic flux intensity treatments

The microstructure of concrete materials showed that magnetic treatment to fresh concrete can strongly influence physical properties such as stronger bond of cement gel to filling materials and it showed surface of material as revealed without any cracks with a better interlocking, as presented in Figure (9).



A) Un treated microstructure **B) Treated microstructure**

Figure (9): Comparison of microstructure of untreated and treated concrete mixes

6. Conclusions

In the current study, a new technology of treated concrete prepared using the static magnetic field treatment was experimentally presented and investigated; this treatment is conducted by a device quite similar to MRI device. The effect of various magnetic treatments (0, 0.04, 0.08, 0.12 and 0.15 Tesla) to the fresh and hard concrete characteristics was quantified. Methodology of the current proposal is to manipulate the placing process of the fresh concrete samples, while maintaining the same materials with the same other configurations. Results showed that directly applying magnetic field on concrete could increase the compressive strength in about 4-19%, simultaneously the flow showed significant improvements. Magnetic treatments of 0.08 and 0.12 Tesla for fresh concrete mix showed a better flow ability with higher increases in concrete strength as compared to other range of magnetic treatments. Unlike, the magnetic treatments could be detrimental for some other range of treatments especially at long-term performance in terms of strength (0.15T treatment rang), however but not in flow. These enhancements in the mechanical properties of concrete was due to enhancement the microstructure of concrete materials magnetic fields disperses cement particles from hydration layers surrounding the filling particles, at the same time increases their molecular internal energy to breaks and/or change some of the hydrogen bonds, resulting in more separate water molecules. However, the results could become a base for further studies aims to construction of a new generation of smart materials with unique property.

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