Mathematical Modelling of Engineering Problems
Vol. 11, No. 3, March, 2024, pp. 689-695
Journal homepage: http://iieta.org/journals/mmep

Enhancing Compressive Strength of Sulfate-Rich Concrete Using Electromagnetic Fields

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https://doi.org/10.18280/mmep.110313

Received: 24 July 2023
Revised: 27 September 2023
Accepted: 15 October 2023
Available online: 28 March 2024

Keywords:
electromagnetic field intensity, sulfate-rich concrete, compressive strength, magnetized water, tap water

ABSTRACT

Concrete deterioration due to sulfate attack is one of the factors for early failure. Considering that sulfates in aggregates are the most important problem related to concrete in the cities of the Middle East and especially Iraq, so there was a need to develop a device to enhance the strength of concrete. In the current experimental research, we sought to discover how to treat and improve the performance of fresh concrete containing high percentages of sulfate salts in sand, using a magnetic field generation device with an electrical principle made locally. The work included the beginning of casting 27 models of concrete cubes that were treated using different magnetic intensities and examined to select the highest strength, which was 3000 Gauss, which was adopted in this research. Two groups of mixtures were prepared and poured using 72 cubes and prisms. The first group was divided into two reference mixtures not treated with a magnetic field. Two types of sand with different sulfate ratios with resistant Portland cement were used. The second group was prepared using the same method and working conditions, except for treating the concrete mixture with electromagnetic fields. The results showed an encouraging improvement in the compressive strength of magnetically treated concrete, where the rates of increase in compressive strength were (5.45, 5.5, 5.7%) with 0.15% SO_3, and (7.2.7, 4.6%) with 0.6%. SO_3 for a period of (7.28 and 90) days, respectively, compared to control mixtures. This technology can be applied during the pouring process on job sites.

1. INTRODUCTION

Deterioration of concrete due to sulfate attack is one of the factors of early failure, due to its reaction with cement hydration products and formation of an ettringite. This motivated most researchers to produce concrete structures that correspond to the ideals of sustainable development, while also being affordable, highly effective, and ecologically friendly using magnetized water technology in a variety of methods, in order to reduce the impact of sulfates, especially sulfate aggregates.

The main objective of this study was to find out if a magnetic field-generating device with an electric principle could enhance the strength of sulfate sand- rich concrete.

Magnetized water was employed in every previous experiment to improve the characteristics of concrete. The current investigation involves the use of an electromagnetic field to treat fresh concrete mix, by mixing tap water with concrete and then placing the resulting slurry in an electromagnetic field to create magnetized concrete.

The need for concrete components has increased along with the demand for building development, where there is an urgent need for concrete, and the increasing use of sand, has become an issue of great concern and danger because it may have negative environmental effects [1].

Understanding the impact of magnetism on water is essential to assess its effects on concrete properties.

Before the magnetic field treatment of water may be turned on, Huchler and Lawrenceville [2] state the following three conditions must be satisfied: Water's time in a magnetic field, the magnetic flux density, and the current speed all play a role.

Water that has been exposed to a magnetic field is said to be magnetic, not that it has developed a magnetic force. That altered the peculiar characteristics of water. The hydrogen bond groups are broken and the binding angle is decreased by the magnetic field, which alters the density of water and makes it more soluble [3].

The magnetized water undergoes structural changes as the amount of its surface that is exposed to the magnetic field grows. It causes a noticeable boost in compressive resistance when utilized in concrete rather than regular water. Concrete's requirement to use less cement is addressed by the increased resistance created by the use of magnetized water [4].

Due to the special anomalous qualities of water, it changes certain of its (physical and chemical) characteristics when subjected to a magnetic field. Each cluster of molecules that makes up water is determined exclusively by the compulsion, potency, and temperature circumstances that exist over the water. It is believed that water is a homogeneous mixture consisting of two hydrogen atoms coupled to one oxygen atom and has a transparent appearance. Vander Waal forces and hydrogen bonds hold these molecule clusters together. Clusters break apart into even smaller clusters when subjected to a magnetic field, changing several properties of water [5].

As the surface area of the water exposed to the magnetic field grows, structural changes are seen in the magnetized water. It significantly increases compressive resistance when used in concrete in place of regular water. The demand to use less cement in concrete is addressed by the increased resistance that results from the use of magnetized water.

After 28 days of curing, using magnetized water instead of tap water greatly boosts the compressive strength of the concrete, increasing by 30.07% for 2T of magnetized water and 14.35% for 0.986T of magnetized water [6].

Although cement is reduced by up to 25%, it has been discovered that magnetized water increases the compressive resistance of concrete. Additionally, it was discovered that concrete produced using magnetic technology is simple to use and retains its compressive strength [7].

During the mixing and curing phases of the concrete preparation process, water plays a number of crucial roles. This can be changed into "magnetic water" by being exposed to a magnetic field. Furthermore, as bond angles change, molecule group sizes alter (falling from 13 to around 5 or 6 molecules), boosting viscosity and surface area and quickening the hydration process. Normally, the orientation of tap water molecules is arbitrary, but after "magnetization," they are all pointed in the same direction [8].

According to the "light spectrum," water molecules are made up of one oxygen and two hydrogen atoms that are held together by a single triangle with an angle of around (104.5°), which falls to 103° when exposed to a magnetic field. The magnetic field causes the bond pairs to move in closer proximity, which causes this to happen [9].

Compressive strengths of tap water and magnetized water were 5.5 to 32.5 MPa, initial setting times were 4 to 32 minutes, and ultimate setting times were 303 to 546 minutes [10].

According to a study (Karam and Al-Shamali), using magnetic water instead of ordinary tap water increased the compressive strength of concrete by 10 to 15%. Other mechanical parameters, such as strength in flexure and splitting tensile strength, were also improved by 7 to 28% [11]. The workings of this magnetic water technology are shown in Figure 1.

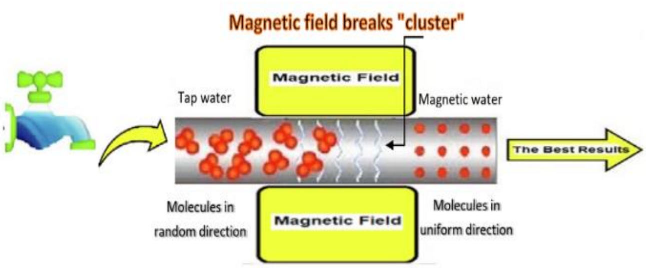


Figure 1. Mechanism of magnetic water technology

The figure above shows a mechanism of action of the magnetic field technique when water passes through it. We notice a change in the size of the water molecules and their rearrangement in one direction after they were random, and this in turn increases the surface area and viscosity of the water. From past research, it is clear that using magnetized water instead of tap water enhances concrete's fresh and hardened qualities without the need for additives while also lowering the cement content.

The main objective of the current study is to apply a novelty approach to improve the strength of sand sulfate-rich concrete, by conducting an experimental investigation of the use of an electromagnetic field to make magnetized concrete, by passing fresh concrete through a tube of a locally made device and evaluating the effect of magnetization on the improve properties of concrete.

2. EXPERIMENTAL INVESTIGATIONS

2.1 Constituent materials

2.1.1 Cement

Al-Mass" Sulfate Resistance Portland cement was used in this project. The precise chemical and physical parameters, which fall within the boundaries of Iraqi standard standards, are shown in Tables 1-2 [12].

Table 1. Cement's chemical composition of SRPC

Test Name	Contents (by Weight %)	Limits of Iraqi Specification NO.5/2019 (42.5 R)
Lime (CaO)	62.10	---
Silica (SiO_2)	20.30	---
Alumina (Al_2O_3)	4.07	---
Iron oxide (Fe_2O_3)	5.17	---
Magnesia (MgO)	1.75	≤5.0 %
Sulfate (SO_3)	2.33	≤ 2.5% if C_3A ≤ 3.5%
Loss on Ignition (L.O.I.)	3.61	≤4.0 %
Insoluble residue (I.R.)	0.55	≤1.5 %
OPC' Main Compounds (Bogue's Eq.)		
Tricalcium silicate (C_3S)	63.73	---
Dicalcium silicate (C_2S)	10.27	---
Tricalcium aluminate (C_3A)	2.04	≤3.5%
Tetracalcium alumino-ferrite (C_4AF)	15.74	---

Table 2. Physical properties of SRPC

Test Name	Results	Limits of Iraqi Specification NO.5/2019 (42.5 R)
Fineness (Blaine method), (m^2/kg)	335	≥ 300
Setting time (Vicat's method),		
Initial setting time (hr.: min)	2:23	≥ 45
Final setting time (hr.: min)	3:10	≤ 10
Compressive strength (MPa),		
Early strength (2 days)	25.4	≥ 20
Standard strength (28 days)	44.30	≥ 42.5

Table 3. The fine aggregate's physical and chemical characteristics

Test Name	Sample 1	Sample 2	Limits of Iraqi Specification No. 45/1984
Sulfate content [%]	0.15	0.6	≤ 0.50 %
Specific gravity	2.58	2.58	-
Fineness modulus	2.61	2.58	-
Absorption [%]	0.78	0.80	-

2.1.2 Sand

The concrete mixtures used in this work, which fall under zone (2) and were created using sand grains with saturated and dry surfaces (see Table 3), show that the sand's physical and chemical properties were within the parameters of the Iraqi standard specification [13].

The sand sulfate percentages were tested in the laboratory and for several samples, the lowest percentage was chosen within the specified specification (0.15%), and a high sulfate percentage outside the specification was chosen (0.6%), in order to compare the results after conducting the magnetic treatment of the fresh mixtures.

2.1.3 Crushed gravel

Under wet and surface-dry circumstances, this experiment was carried out with crushed aggregate having a nominal maximum size of 20 mm. The sample's physical and chemical characteristics are listed in Table 4, and each one was within the permissible range according to Iraqi standard specification [13]. In the University of Babylon's construction materials lab, experiments were put up.

Table 4. Characteristics of crushed aggregate

Properties	A Test Result of Sample	Limit of the Iraqi Specification No. 45/1984 (5-20) mm
Specific Gravity	2.7	-
Sulfate Content, SO_3 [%]	0.03	≤ 0.1 %
Dry Rodded Density [kg/m³]	1650	
Absorption [%]	0.52	-

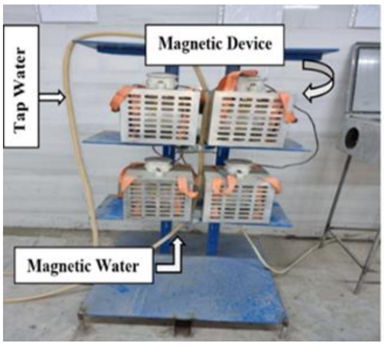
2.1.4 Blending water

For concrete mixing and curing, tap water from the water delivery system was used [14]. Magnetized water was produced by exposing tap water to an electromagnetic field with an intensity of 3000 Gauss, as measured with a Tesla meter, through a 0.5-inch diameter plastic tube in the center of the electromagnetic apparatus, as illustrated in Figure 2 (a) and (b).

Normal (non-magnetized) concrete was cured using tap water, while magnetized concrete was cured using magnetized water. To maintain the magnetized healing water's characteristics, it was changed every three days.

2.2 Design mix

A reference mix with the necessary cylinder compressive strength of 30 MPa was made using ACI [15], and after being aged for 28 days, it produced a cube compressive strength of 37.5 MPa. The cement-to-water ratio in each of the combinations was 0.43; the slump values ranged from 75 to 100 mm. They also included 1,024 kg/m^3 of crushed aggregate, 699 kg/m^3 of fine aggregate, and 417.52 kg/m^3 of cement. Two types of concrete were created for this study; the first type was divided into two mixtures of reference (non-magnetized) concrete, and the second type was divided into two mixtures of magnetized concrete that were exposed to the device's electromagnetic field. Each treated concrete mix included sand from one of two varieties, each of which had various amounts of sulfate salts (0.15, and 0.6%). It was contrasted with the two reference concrete mixtures, which also contained sulfate salts in various ratios.



(a)

(b)

Figure 2. (a) The apparatus for preparing electromagnetic water; (b) The tesla meter for measuring the magnet's intensity

Figure 3. Testers for compression

Figure 4. Flexure test equipment

2.3 Preparation of specimens

The investigation was conducted using prismatic 100×100×500 mm and cubic 150 mm templates. The compaction, casting, and curing of 99 concrete samples were completed in accordance with the necessary standards [16, 17]. In order to determine the highest intensity, "27" samples were cast to test the compressive strength when using three intensities of magnets to treat the fresh concrete mixture to determine the highest strength for three ages. 18 samples to test the compressive strength of the concrete mixture treated with the electromagnetic field using the magnetic strength of 3000 Gauss and 18 samples for the untreated reference mixtures. 18 prism samples of the electromagnetically treated concrete mix and 18 prism samples of the untreated reference mix were used for the flexural strength test. Concrete that had been treated with magnetization was cured in a tank of magnetized water, while untreated (non-magnetized) concrete was cured in a tank of tap water.

2.4 Testing specimens

Cubes' compressive strength is evaluated according to the reference [18], and flexural strength of the prism according to the reference [19], this occurs at 7, 28, and 90 days. Figures 3 and 4 depict the test devices.

The experimental work focused on studying and examining two types of concrete (untreated reference mix and electromagnetic field treated mix), each type of mix consisted of 36 samples, including 18 cubes and 18 prisms. Figure 5 shows the experimental work scheme for this study.

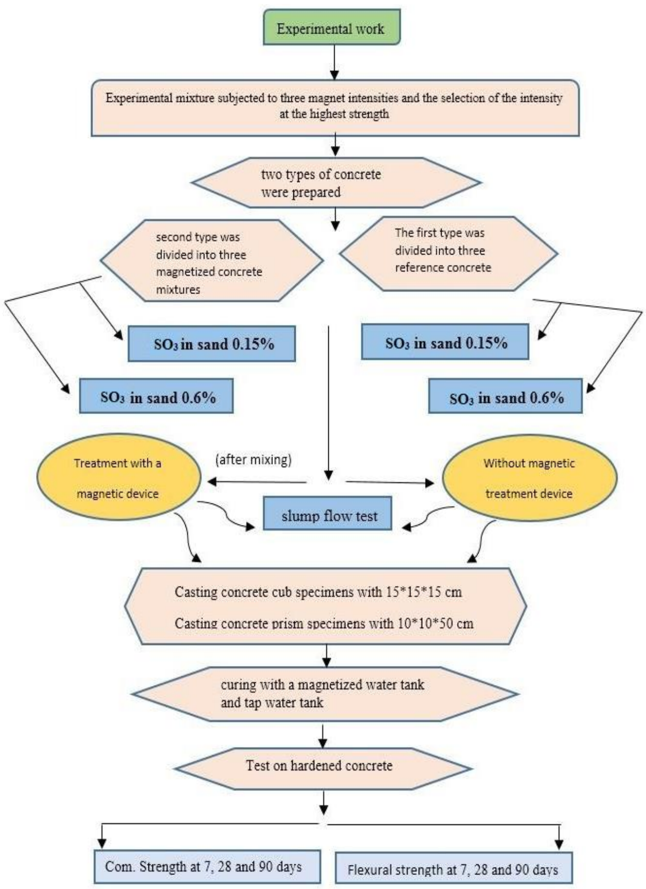


Figure 5. Flow chart of the experimental work

2.5 Choose the intensity

To evaluate the effects of fresh concrete exposed to an electromagnetic field, the compressive strength test was conducted for hardened concrete with an age of (7, 28, 90) days, Table 5 demonstrates this. Using three electromagnetic intensities (2000, 2500, 3000) Gauss. Several preliminary tests were conducted to determine the intensity, by calculating the voltage of the incoming electric current with the intensity of the generated electromagnetic field. A Tesla meter was used to check the intensity of the electromagnet's field at each stage.

Table 5. Apply several magnet intensities against the compressive strength

Intensity (Gauss)	Age of Test (Days)		
	7	**28**	**90**
First Intensity (2000)	34	40.8	45
Second Intensity (2500)	36.3	43.6	48
Third Intensity (3000)	38.8	46.6	51.87

Concrete was exposed to a magnetic intensity of 3000 Gauss, which produced the highest compressive strength; this intensity was used in the tests that followed.

2.6 Create an electromagnetic field generation device

Four locally manufactured magnets, each with a copper coil around a wrought iron core (length=20 cm, and diameter=9 cm), and entirely insulated by a clip insulator to ensure safety and lower heat generation when the device is used in a lab, make up the device, which is connected in series. The operating box, which houses the device's main circuit breaker and secondary circuit breaker number 3 for three levels of magnetic intensity, is attached to it. To lower high temperatures when operating for extended periods of time, it also has side fans and heat reducers. Figure 6 depicts the operation box's component pieces as well as the final shape and details of the magnet piece as it is wound with wire.

A 220-volt direct electric current was used to power the apparatus. A generator or batteries may also be used to power the device. The device's box attachment contains the primary operational switches (the main circuit breaker), which operate in a closed circuit with one of the lines linked to a row of magnets and the other line to a heat sink. In order to increase the magnetic field intensity in three phases, it also incorporates three secondary circuit breakers. Three different magnet intensity values were tested and confirmed during the course of the work, with readings of 2000, 2500, and 3000 Gauss from a magnetic wave measuring equipment (Tesla meter). 60 cm high and 4 inches in diameter make up the treating area of the concrete mixture that is exposed to the electromagnetic field as it passes through the device.

2.7 Magnetic treatment for fresh concrete

The fresh mixture was split into two equal portions after each concrete mixture had been thoroughly mixed using sand with a specific sulfate ratio. The first portion of the mixture was then pumped through the tube of the apparatus subjected to a magnetic field strength of 3000 Gausses. The fresh mixture was transferred directly from the mixer to the device by means of a large ladle, and pumped into the tube through a funnel located at the top, after which a slump test was carried out, and the concrete was then poured into the molds. The other part It was poured directly into the mold After conducting a slump test the upper face of the mold was flattened to remove an extra mixture.

A clear increase was observed for the slump test between the treated fresh mixture and the untreated reference fresh mixture.

Figure 6. Details of the electromagnet device

3. RESULTS AND DISCUSSION

3.1 Impact of magnetic field intensity on concrete properties

According to the study, The strength properties of magnetized concrete increase with increasing electromagnetic field intensity. Concrete workability, compressive strength, and flexural strength were tested. The slump flow test for fresh concrete was carried out according to the reference [20].

One of the key qualities of concrete is its compressive strength. The outcome of the current experimental study on concrete was its response to magnetic curing. where CTr, CTr* (non-magnetic mixture) and TWTr, TWTr* (magnetized mixture) types of concrete were created. The first type of CTr was split into two reference mixtures, each of which used a sample of sand with a different amount of sulfate salts (0.15, and 0.6%), and which mixed the concrete with tap water. The same procedures were used for the second type of TWTr, which was divided into two mixtures, with the exception that the finished concrete was subjected to an electromagnetic field by being pumped through the tube's diameter (10 cm). According to Table 6 and Figures 7-10, the mixes TWTr demonstrated greater compressive and flexural strength than the reference mixtures CTr at 7, 28, and 90 days.

Table 6. Concrete's compressive and flexural strength (MPa) for SRPC

Description			Test (MPa)	Age at Testing (Days)		
				7	28	90
CTr	With SO_3=0.15	Without magnetic Treatment	Compressive strength	39.30	44.3	49.67
			Flexural strength	2.46	4.74	5.78
TWTr		Magnetized mixture	Compressive strength	41.44	46.73	52.5
			Flexural strength	2.78	5.42	6.22
CTr*	With SO_3=0.6	Without magnetic Treatment	Compressive strength	38	43	49.21
			Flexural strength	2.4	4.54	5.6
TWTr*		Magnetized mixture	Compressive strength	40.74	46	50
			Flexural strength	2.7	5.4	6.14

3.2 Validation of curing fresh concrete mix with magnetic field using electric principle

When examining and analyzing the findings of this study regarding the qualities of flexural and compressive strength following the applied electromagnetic field treatment process for the fresh concrete mix and compared with the experimental results of previous studies [21]. it can be noted that the compressive strength increases for the current study for samples that were prepared using tap water and treated with an electromagnetic field and cured in tank water magnetized. Table 7 shows how compressive and flexural strength for magnetized mixes have increased by a given %.

Table 7. Compressive and flexural strength and the effects of electromagnetic therapy (TWTr, TWTr* percentage increase against CTr, CTr*)

Test	Age of Test (Days)		
	7	28	90
Compressive strength with SO_3=0.15 TWTr	5.45	5.5	5.7
Compressive strength with SO_3=0.6 TWTr*	7.2	7	4.6
Flexural strength with SO_3=0.15 TWTr	13	15.35	8
Flexural strength with SO_3=0.6 TWTr*	12.5	18.9	9.6

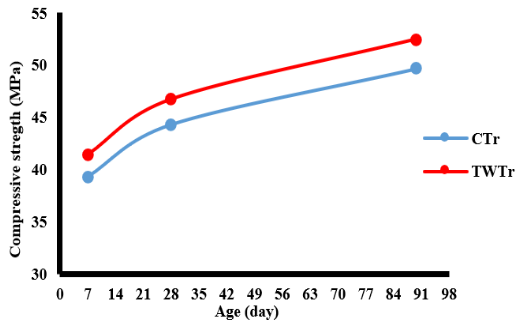


Figure 7. Compressive strength results for mixes (CTr) and (TWTr)

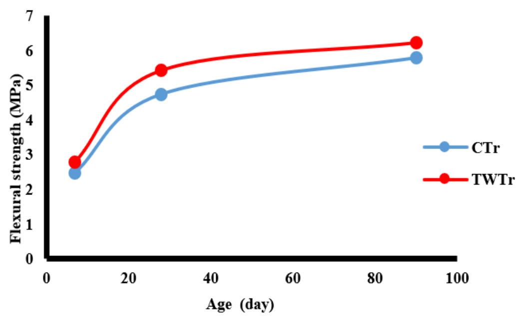


Figure 8. Results for flexural strength: CTr and TWTr mixes in MPa

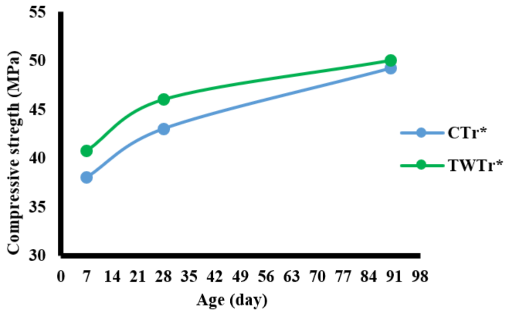


Figure 9. Compressive strength results for mixes (CTr*) and (TWTr*)

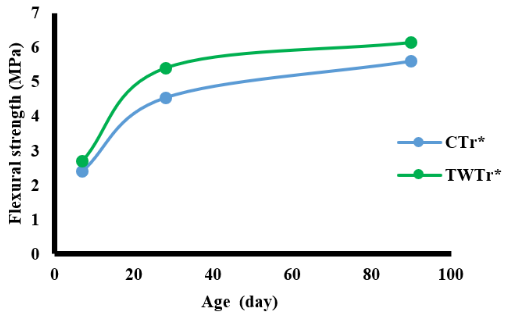


Figure 10. Results for flexural strength: CTr* and TWTr* mixes in Mpa

An electromagnetic intensity of 3000 Gauss was used to produce (TWTr, TWTr*), the working context is illustrated in Figure 11.

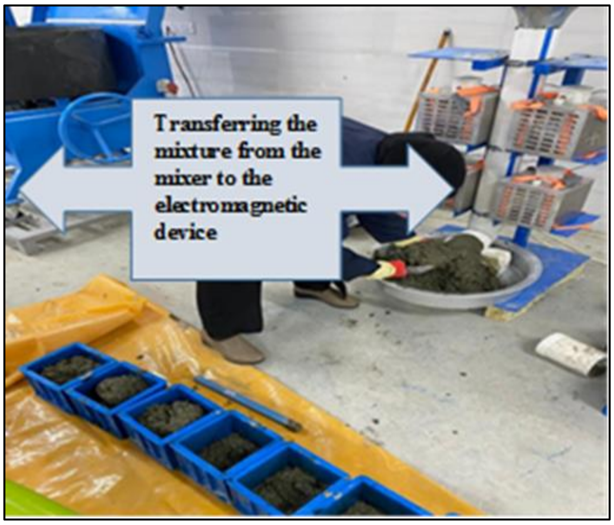


Figure 11. Magnetic concrete processing

Comparing the two mixtures with different quantities of sulfate salts in the sand (0.15, 0.6%) to the reference mixtures with the same proportions, the compressive and flexural strength values of the samples of the second type (magnetized concrete) increased significantly. At (7,28,90) days, the strength of the 0.6% sulfate-containing mixture was comparable with the resistance values of both tests, (7%, 15.35%) The percentage increase in compressive and flexural strength at the age of 28 days is higher than that of the age of 90 days, indicating a low salt episode after 28 days.

It can be concluded that the electromagnetic field charges the water molecules in the magnetized concrete, disperses the water clusters, and creates small clusters with high activity, where the binder particles are Penetration, leading to better cement hydration, which is the cause of the improved mechanical properties of magnetized concrete.

And from previous studies on the effect of using magnetized water in the concrete industry, reasonable agreement with their results was discovered [22]. They report that the magnetic field intensity of MFI improves compressive strength and fracture toughness, amplified by lowering the water/cement ratio and lift (MFI). When making a comparison with (PrM specimens) pre-magnetized specimens [23], an acceptable agreement appeared with the results of the current experimental study regarding the improvement in the percentage of compressive and flexural strength of the magnetized mixtures.

The results of this pilot study indicate that the comparison with the effect of using electromagnetic treatment is highly acceptable in terms of the desired efficiency of the current practice.

It is also possible to produce concrete with high specifications when using sand containing high sulfate ratios by using electromagnetic treatment to improve the properties of concrete.

When employing sand with various sulfate ratios, it is also possible to manufacture concrete that meets strict criteria by electromagnetically enhancing the concrete's characteristics.

4. CONCLUSIONS

Experimental research has been done on the impact of applying various magnetic intensities on the compressive strength of concrete. Reference concrete mix and electromagnetic wave treated concrete mix were the two types of concrete mixtures that were created. The findings of this experimental study are compelling, leading to the following conclusions regarding the treatment of fresh concrete.

1) Regular concrete's mechanical qualities (compressive and flexural strength) are greatly enhanced by magnetized concrete technology without the need for extra materials. The improvement in strength is due to the efficiency of the hydration process. After exposure of the mixture to the electromagnetic field, the cement gel disperses and forms better groups and the trapped mixing water flows to facilitate the distribution process and completion of the hydration process more, thus reducing the attack and interaction of sulfate salts to form ettringite after the concrete hardens.
2) At test ages of 7, 28, and 90 days, the compressive strength of concrete made with tap water and treated with an electromagnetic field by passing it through the device's tube at an intensity of 3000 Gausses increases by approximately (5.45, 5.5, 5.7%) with SO_3 0.15%, and (7.2,7, 4.6%) with SO_3 0.6.
3) Compared to the reference concrete mixes, the flexural strength of concrete made with the same electromagnetic field-treated mixture increased by approximately 13, 15.35, and 8% for SO_3=0.15; and 12.5, 18.9 and 9.6% for SO_3=0.6.
4) Due to the positive effects of the electromagnetic field that charges the water molecules in concrete, it is possible to draw the conclusion that raising the electromagnetic field's strength enhances the mechanical properties at different rates.

5) By exposing a portion of the concrete pump tube to an electromagnetic field, this technology can be used to pump concrete efficiently during the pouring process.
6) Based on the results of the current study, subsequent studies can be conducted that include the effect of electromagnetic curing on the long-term durability of concrete and its effect on permeability and shrinkage.
7) Use of the new approach to enhance the strength of sand sulfate-rich concrete is effective in reducing the effect of sulfates and increasing the durability of concrete, in addition to that the methods of magnetic treatment are affordable and harmless to the environment.

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