

# Effect of magnetic treatment of mixing water on the behavior of cement-based materials: A review

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Magnetic treatment technology for concrete mixing water is a cost-effective and environmentally friendly approach that can enhance the performance and durability of cement-based materials. This technology aligns with the principles of sustainable development. In their studies, researchers have utilized static magnetic fields (SMF) of varying intensities to treat regular water and produce magnetically treated mixing water (MTMW) for a specific duration. Various research laboratories have successfully employed MTMW in the production of cement-based materials such as cement paste, mortar, ordinary concrete, foam concrete, self-compacting concrete, and rubber concrete. The main objective of this investigation is to review previous research that evaluated the impact of MTMW produced using different methods on the fresh, hardened, durability, and microstructure properties of cement-based materials. Most studies revealed that magnetic treatment technology improves physical and chemical properties of regular water, including solubility, surface tension, and conductivity. Regarding cement-based materials produced with MTMW, most investigations have demonstrated a significant enhancement in mechanical strength, durability, and microstructure. However, it seems that some researchers may have exaggerated their findings regarding the effect of MTMW on mechanical properties. Consequently, further research is needed to validate these results. I recommend considering the utilization of the MTMW technique for all cement-based materials to enhance their mechanical strength and durability performance.

Keywords: *cement-based materials, magnetic treatment, magnetically treated mixing water, physiochemical properties of water, fresh properties, mechanical performance, durability*

## 1. Introduction

Cement-based materials play a crucial role in the construction industry because of their significant importance in providing structural strength and durability. These composites, typically formed by combining cement with other materials such as aggregates, mineral additions, admixtures, and fibers, offer a wide range of benefits including increased load-bearing capacity, fire resistance, and reduced maintenance requirements. However, ensuring their long-term performance and durability presents several challenges. Recent data highlights the need to address cracking, shrinkage, and degradation caused by environmental exposure, chemical attack, and mechanical strength [1, 2]. In concrete technology, mixing water has a crucial impact on the quality of cement-based

materials, affecting their mechanical and physical performance in both the fresh and hardened states. Moreover, mixing water is essential to ensure appropriate consistency and correct placement of cement-based materials [1–4].

Throughout the 20<sup>th</sup> century, natural resources such as water, minerals, and fossil fuels were excessively exploited. These negative practices have led to the pollution of vital sources of life on our planet, especially surface and groundwater [5, 6]. On the other hand, the use of chemicals to disinfect and sterilize water led to a decrease in its quality and effectiveness in interaction with other materials such as cement [3, 4, 7]. In addition, the transmission of water at high pressure from tower water to concrete factories through the public network leads to specific changes in their characteristics. These changes manifest as contamination indicators such as higher surface tension, solidification, and increased turbidity of the water

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molecules [3, 4, 7, 8]. As a result, ensuring the availability of clean water for industrial activities, including concrete production, remains a significant challenge in the field of construction materials [5, 7, 8].

Various techniques have been employed to treat mixing water in research, including mechanical, chemical, thermal, electrical, and magnetic treatment [9–13]. Many studies revealed that magnetic treatment, in particular, shows promising potential in activating the behavior of cement-based construction materials [19–21]. By exposing the mixing water to a static magnetic field, researchers have successfully improved properties such as consistency, strength, and durability [22–25]. Magnetic treatment involves subjecting water to a magnetic field, aligning its molecules and reducing their size. This leads to lower surface tension, viscosity, and boiling point. These changes positively impact the behavior of cement-based materials by facilitating deeper penetration into cement grains, enhancing the hydration reaction, and improving the microstructure. This trend results in better packing of cement past particles, reduced porosity, and a more uniform distribution of hydration products. Research findings suggest that the application of magnetic treatment exhibits potential in improving the mechanical strength, endurance, and pliability of cement-based substances [13–18]. However, certain aspects related to the process of magnetic water treatment have raised considerable confusion. These points include: Which pole should be utilized to achieve the optimal magnetic effect? How many times should water pass through the static magnetic fields (SMF) to achieve the optimum effect? What is the optimal intensity of the magnet that gives the best results? What is the recommended duration for the magnetic activation process? How long does water retain the magnetic effect after magnetic treatment?

On the basis of previous research conducted in this field, this review aims to provide answers to the questions mentioned above. It summarizes the effects of magnetically treated mixing water on the physical, mechanical, and durability performance of cement-based materials. Furthermore, it

analyzes and offers insights on various techniques employed to treat mixing water using a magnetic field and their impact on the physical and chemical properties of water. Additionally, this paper emphasizes the significance of water magnetic treatment technology and encourages cement-based materials producers to integrate it into the concrete manufacturing process.

## 2. Water magnetic treatment technology

Water magnetic treatment technology, also known as magnetized water, involves treating water with a magnetic field to enhance its properties. The resulting water has been referred to by various names in the literature, such as magnetically treated water, activated magnetic water, living water, magnetic water, and wonderful water [14, 18–21]. Magnetic treatment has been found to significantly impact the properties of water. When water is exposed to a magnetic field, its molecules align in a single direction and reduce in size compared to that of regular water [13, 14, 18–20]. This alignment and reduction in size lead to several changes in the properties of MTMW [13, 14, 17, 18]. Proponents of magnetic treatment water technology claim that it offers a wide range of benefits, including enhancing the performance of cement-based materials [14, 17, 18, 22]. The magnet can be placed in the water or near it [14, 17, 18, 22–24]. Furthermore, some researchers reported that magnetically treated mixing water (MTMW) contains higher levels of ( $\text{OH}^-$ ) ions, which could be the reason for the enhancement of all its properties [9, 14, 24]. There are various methods and technologies that have been used to magnetically activate the mix water during the production of cement-based materials [14, 18, 22–24]. These techniques aim to enhance the performance of the resulting cement-based materials. The review of previous studies revealed that researchers have employed many techniques to prepare the MTMW [9, 24–26]. The following sections present some commonly employed methods.

## 2.1. Permanent magnet

The first method for obtaining magnetically treated water is by placing permanent magnets in contact with a glass container filled with water for a specified period (Fig. 1). This method involves exposing the tap water to a static magnetic field created by either permanent magnets or electromagnets. When water comes in contact with a glass container, the magnetic effect is transferred to the water molecules. The revision of previous research papers has revealed that water treated with either the north or south pole or the two poles together have different physicochemical properties [24–30]. Many studies, however, do not differentiate between water treated with the south pole, north pole, or both poles [25, 28, 29]. For this reason, I noticed a significant differences among the properties of magnetically treated water. Some studies [23, 27–32] had used only one pole, either the north or south pole, to activate tap water. The north pole (the negative pole) is responsible for increasing the pH value towards alkalinity [26–28], while the south pole (the positive pole) can contribute to increased acidity of water treated with a magnetic field [13, 28, 29]. In order to obtain the optimum effect of magnetic treatment, several researchers have recommended using bipolar magnetically treated water [15, 31].

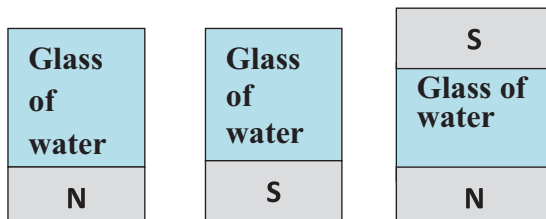


Fig. 1. Different methods of magnetic treated water by poles: north pole (N), south pole (S), and bipolar (N-S)

## 2.2. Flow of water passing through a magnetic field

This technique involves passing water through a pipe that is subjected to a static magnetic field generated by magnets placed parallel to each other around the pipe (Fig. 2). The water flows through

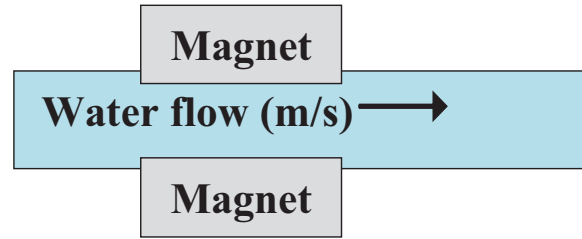


Fig. 2. Magnetic treatment by means of passing water through a magnetic field

a SMF slowly, either once or multiple times, until the desired magnetic intensity is reached. Many researchers have recommended this technique because it results in highly energized water [33–35]. Additionally, this method is more practical for construction sites than other techniques. In the first technique, the water is stationary and is subject to a constant magnetic field, while in the second technique, the water is passed once or more times over a magnetic field at a constant speed. I noticed that many studies [7, 17, 25, 27, 36–40] reported that water passed through a pipe that was subjected to a magnetic field, but do not specify how the magnetic field was obtained. Is the pipe in contact with the north or south pole, or does the magnetization tool contain two opposite poles, as shown in Figure 2? Therefore, there is great ambiguity regarding this important point in many studies that use this technique.

## 2.3. Magnetic field treatment device

Many studies, [10, 18, 37, 42, 43] have used the magnetic field treatment device (MFTD) to produce magnetically treated water. This device utilizes a magnetic field to activate mixing water for cement-based materials. The MFTD consists of permanent magnets or electromagnets that generate the magnetic field, causing changes at the molecular level. It is believed that the alignment of water molecules improves water quality, enhancing the hydration process and workability of cement-based materials [37, 42, 43]. The MFTD also influences the hydration kinetics, leading to accelerated early-age strength development and improved long-term durability. Additionally, they affect the rheological properties of cement composites, such as viscosity,

flow ability, and setting time, which can be advantageous in terms of workability and application suitability. Some studies suggest that using MFTD can lead to improved mechanical properties and reduce the water/cement ratio required, resulting in cost savings, and environmental benefits [37, 42, 43]. While magnetic stirrers, magnetic water conditioners, and magnetic impulse treatment are alternative methods for activating water using magnetic fields, there are no research papers that explore their specific impact on the properties of cement-based materials.

### 3. Parameters influenced the magnetic treatment of water

A review of previous studies [9, 10, 31–36] revealed that the effectiveness of magnetic treatment technologies may vary depending on factors such as the strength and duration of the magnetic field, the distance between the magnets, the water flow rate, and the specific characteristics of the cement-based materials being produced. Further research and experimentation are necessary to determine the optimal method and parameters for magnetically treating the mixing water in different production scenarios. In this section, I consider the parameters that may affect magnetically treated water.

#### 3.1. The SMF intensity, distance between the poles, and speed of flow

Ahmed et al. [44] conducted a study to investigate the combined effect of silica fume (SF) and magnetically treated water (MW) on concrete properties. They compared the results of using regular water (RW) and MW produced by passing RW through an SMF with intensities of 1.4 tesla and 1.6 tesla (T) for 100, 150, and 250 cycles. The study revealed that magnetic treatment significantly increased the compressive strength, splitting tensile strength, and flexural strength of the concrete by up to 80%, 98%, and 22%, respectively. The best results were obtained when RW was passed through a magnetic field with an intensity of 1.6 T for 150 cycles. In another study, Zhao

et al. [43] prepared concrete using magnetized water treated with different SMF intensities up to 1.5 T. Their experiments showed that concrete mixtures prepared with a SMF intensity of 1.5 T had lower hardening properties compared to those prepared with magnetized water subjected to an SMF intensity of 1.2 T. Ibrahim [33] conducted research on treating distilled water with a bi-polar static magnetic field with intensities ranging from 0.2 to 5000 gauss (G). He found that increasing the flow speed resulted in a decrease in SMF intensity and increasing the distance between the poles also led to a decrease in SMF intensity. Raouf et al. [34] discovered a positive correlation between the SMF intensity and the fresh, hardened, and durability properties of concrete, with SMF values ranging from 0.4 to 0.8 T. In a recent study, Karthik et al. [28] observed similar results in self-compacting concrete prepared with magnetized treated water exposed to SMF intensities ranging from 0.6 T to 1.2 T.

#### 3.2. The magnetic treatment time

Several studies investigated the optimal duration of exposure to an SMF for regular water to achieve the best magnetic treatment effect on cement-based materials properties [25, 28, 36, 43, 46]. Wang et al. [43] found that the effectiveness of magnetic treatment on water molecules increases up to a certain duration of exposure, after which the link between water molecules weakens. Malathy et al. [25] exposed water to an intensity of 0.9 T for different durations and determined that 60 min exposure resulted in the highest compressive strength of concrete. Yousry et al. [36] investigated the impact of MTMW on the compressive strength of mortar composites with fly ash (FA). The MTMW was produced by passing normal water through an SMF with an intensity of 0.8 T. They found that the highest compressive strength increase, up to 60%, was achieved with 150 cycles at 56 days for mortar without FA content. Reddy et al. [46] exposed regular water to an SMF of 985 G for varying durations and reported that a 24-hour exposure period yielded the highest compressive strength

of concrete. Karthik et al. [28] produced self-compacting concrete using MTMW exposed to an intensity of 985 G for 24 hours. The results showed that magnetized concrete had improved workability, 10% higher compressive strength, and was more cost-effective compared to concrete prepared with unmagnetized water. In summary, previous studies revealed that magnetic treatment enhances the properties of water and cement-based materials. However, further investigation is needed to determine the optimal duration of magnetic treatment for achieving the best performance of cement-based materials.

### 3.3. The storage time of MTMW

Several studies [14, 30, 34, 43] have investigated the duration for which magnetized water retains its magnetic properties after exposure to a magnetic field. All these studies reported that magnetized water gradually loses its magnetic properties over time and reverts back to regular water. The rate of demagnetization is influenced by factors such as the intensity of the static magnetic field (SMF) and the storage conditions. Some studies [14, 30] found that the magnetic energy of water can persist for up to 48 hours after magnetic treatment, while others have observed that the magnetic effect can last for a few minutes to several hours [14, 30, 34, 43]. Abdel-Raouf et al. [34] stored magnetically treated water for three days and found that concrete produced with this water had lower performance compared to concrete produced with freshly magnetized water.

## 4. Physiochemical properties of the MTMW

It is important to note that the changes in the physicochemical properties of the MTMW may vary depending on the strength and duration of the magnetic field exposure, as well as the composition of the water and any solutes present in it. In this section, we revised the previous studies about the influence of SMF on some properties of regular water as pH, surface tension, solubility, conductivity, and so forth.

### 4.1. Surface tension

There are numerous studies in the literature investigating the impact of magnetic treatment on the surface tension of regular water [40, 44, 47–50]. Liu and Cao [47] discovered that subjecting pure water to an SMF of 300 mT intensity for 15 min resulted in a 25% decrease in surface tension. Bharath et al. [48] found that passing normal water through a 1.0 T magnetic field at a flow rate of 1.32 m/s reduced surface tension by 7.77%. Wei et al. [49] reported a 4.6% decrease in surface tension when normal water was exposed to a 260 G magnetic field. Recent studies have also reported similar findings. In contrast, Fujimura and Iino [50] studied the surface tension of water–air interfaces exposed to a 10 T magnetic field intensity, and their results showed a slight increase in surface tension by  $1.83 \pm 0.18\%$ .

Most review studies have confirmed that magnetically treated water experiences a decrease in surface tension, with the extent of reduction depending on the static magnetic intensity and treatment time. This decrease in surface tension allows magnetically treated water to spread and be absorbed more easily by materials. This property can be beneficial in cement-based composites as it improves the wetting and bonding between water and cement particles.

### 4.2. pH value

Multiple studies have consistently reported that magnetic treatment results in a decrease in the pH of normal water [25, 28, 40, 43, 44]. For instance, Malathy et al. [25] found that normal water has a pH of 6.3, whereas water treated with a 9000-G magnetic field for one hour had a pH of 7.4. The authors suggested that the presence of OH ions in the water led to increased formation of calcium carbonate, leading to a reduction in acidity in the MTW. Furthermore, the pH value of MTW increased with longer exposure time. Zhao [43] conducted a study using an electrical field to prepare MTW and found that its pH value was higher than that of unmagnetized water. The highest pH value was obtained with the following experimental conditions, including a voltage

of 2400 V, high-frequency signals of 15 MHz, an alternating voltage of 15 V, and a SMF of 650 mT. The MTW maintained its activity for up to 30 min of resting time. Many recent studies [40, 44] reported the same results. On the other hand, Karthik et al. [28] immersed a magnet with an intensity of 985 G in a beaker of water for 24 hours to prepare MTW. Their results showed that magnetic treatment increased the pH of normal water by approximately 5%.

### 4.3. Viscosity

The viscosity, or the resistance to flow, of water is influenced by magnetic treatment. Magnetized water tends to have lower viscosity compared to regular water. Several studies [25, 48] have investigated the effect of magnetic treatment on water viscosity. These studies have reported that a static magnetic field (SMF) can decrease water viscosity by modifying the intermolecular forces between water molecules, resulting in reduced resistance to flow. Bharath et al. [48] conducted an investigation where they passed normal water through a 1 T SMF at a flow rate of 1.32 m/s to prepare MTW. They found that magnetic activation reduced the viscosity of regular water by approximately 6.8%. Additionally, Malathy et al. [25] reported that the viscosity of normal water decreased significantly with increasing magnetic treatment time. The authors attributed this decrease to the magnetic field's ability to reduce internal friction between water molecules, thereby increasing the water flow rate. This reduction in viscosity can enhance the flow and workability of cement-based materials, making them easier to mix and handle.

### 4.4. Electrical conductivity

Numerous studies have explored the impact of magnetic treatment on the electrical conductivity of regular water [25, 33, 44, 48]. Bharath [48] found that exposing tap water to a SMF increased electrical conductivity by approximately 2.9%. Ibrahim [33] varied the intensity of the SMF and observed that both electrical conductivity and dielectric constant of distilled water increased with higher SMF intensities. Ahmed et al. [44] discovered that magnetic treatment

increased electrical conductivity by 1.63% to 6.63% in magnetic water produced by passing regular water through an SMF intensity of 1.4 T and/or 1.6 T for various cycles. On the other hand, Malathy [25] conducted a comprehensive investigation on the effects of exposing normal water to a 0.9 T SMF for different durations. Their results showed a 25.7% decrease in electrical conductivity after one hour. Further research is needed to fully understand the relationship between magnetic treatment and electrical conductivity.

### 4.5. Structure of the water molecules

Several studies [14, 15, 21, 51–53] reported that magnetic treated water has a smaller sized molecules compared to regular water [14, 21]. Another authors [51, 52] explained this trend by the fact that magnetic treatment reduces the attraction force between magnetized water molecules, leading to a decrease in the size of larger molecule clusters. Another investigation conducted by Reddy et al. [15] discovered that magnetic treatment reduced the bond angle of water molecules (H-O-H) from 104.5° to 103°. Australian Fluid Energy [53] also observed that magnetized water molecules have a more uniform volume and a lower degree of consolidation compared to regular water molecules. These good properties of magnetically treated water can improve concrete properties and facilitate their placement in formwork. In addition, the vitality of magnetically treated water can activate the hydration reaction between cement and water and improve mechanical properties of cement-based materials.

### 4.6. Temperature of evaporation rate and boiling point

In a recent study conducted by Ahmed et al. [44] magnetic treatment of water was achieved by passing normal water through an SMF with intensities of 1.4 T and/or 1.6 T for different numbers of cycles (100, 150, and 250). They found that magnetic treatment increased the temperature of the water from 25.4°C to 30.8°C when exposed to a magnetic field of 1.4 T to 1.6 T for 250 cycles. Their results also showed that concrete made with

water treated by subjecting it to the magnetic field for 150 cycles exhibited the highest compressive strength. Another study by Wang et al. [43] explored the effects of magnetic treatment on the specific heat and boiling point of regular water using four types of magnetically treated water. They observed that magnetic treatment increased the evaporation rate and lowered the boiling point of the magnetically treated water in comparison to regular water. They found that the most effective magnetic impact was achieved at a magnetic field intensity of 300 mT. This property can be advantageous in cement-based materials because it reduces the risk of pore formation and trapped air during the curing process. It also enables faster evaporation of excess water, resulting in accelerated setting and hardening of the cement-based materials.

#### 4.7. Solubility

Davis and Rawls [54] discovered that water exposed to a magnetic field had higher solubility compared to regular water. They hypothesized that this property of magnetically treated water could accelerate the breakdown of mineral particles. Further investigations [41, 55–57] have also confirmed that magnetically treated water increases solubility to acids, oxygen, and minerals. Kronenberg [22] observed that magnetically treated water exhibited higher fluidity than regular water, which could potentially enhance the chemical and biological reactions of water with other materials such as cement. This trend has the potential to improve the reactivity and hydration of cement particles, leading to enhanced strength and durability of cement-based materials. However, more extensive research is needed to fully understand the impact of magnetically treated water on water solubility and its potential benefits for cement-based materials.

## 5. Effect of the MAMW on the cement composite behavior

### 5.1. Fresh behavior

#### 5.1.1. Consistency

There have been numerous studies in the literature investigating the effect of MTMW on the

fresh behavior of cement-based materials. These studies, including references [16, 25, 34, 51, 53, 54, 57], have consistently shown that the workability of concrete and mortar composites made with MTMW is higher compared to those made with regular water. For example, Malathy et al. [25] found that magnetically treated water increased the workability of concrete by approximately 20.38%. Similarly, Abed Raouf et al. [34] discovered that the slump of concrete prepared with MTMW subjected to magnetic field intensities of 0.1, 0.2, and 0.3 significantly increased by 20, 70, and 120 cm, respectively. Another study [51] reported that the consistency of mortar made with MTMW increased by 40% compared to mortar made with regular water. The authors attributed this trend to the lower viscosity of MTMW compared to regular water, as mentioned by Davis and Rawls [54] and Al-Shameri [57]. Other researchers have attributed this behavior to the electrical charge of water molecules resulting from magnetic treatment, which improves the interaction between water and cement, as discussed by Mazloom and Miri [16] and in an article from Australian Fluid Energy [53].

#### 5.1.2. Setting time

Sevim et al. conducted a study [38] to examine the impact of magnetized and normal water on the initial and final setting time of fly ash (FA)/blast furnace slag (BFS) cement pastes. They found that magnetic treatment increased both the initial and final setting time compared to composites produced with normal water [38]. The authors attributed this trend to the delayed hydration reaction of FA and BFS, which caused a delay in the setting time compared to cement pastes without FA and BFS. In contrast, Soto-Bernal et al. [58] reported that the initial setting time of cement pastes produced with MTMW was reduced by 15% and 25% when subjected to magnetic field powers of 19.1 and 25.4 G, respectively. The study further confirmed that higher magnetic field intensity resulted in a greater reduction in the initial setting time. In a separate investigation carried out by Hassan [42], it was discovered that the application of MTMW reduced the original setting time of cement mortar

significantly by 60% for a water/cement ratio of 0.4 and by 21% for a ratio of 0.6. Various scholars [14, 25, 59–61] ascribed this phenomenon to the magnetic water's influence during the process of hydration, where it is able to penetrate the innermost structure of the cement particles, resulting in a reduction of their setting time.

## 5.2. Physical behavior

### 5.2.1. Ultrasonic pulse velocity

In a recent study, Ahmed et al. [44] conducted an important investigation to assess the impact of combining SF with MTMW on the relationship between compressive strength and ultrasonic pulse speed. They prepared the MTMW by subjecting regular water to SMF intensities of 1.4 T and/or 1.6 T for 100, 150, and 250 cycles. The optimal magnetic effect was achieved under experimental conditions of 1.6 T and then 1.4 T intensities for 150 cycles. The results of their study revealed a strong correlation between ultrasonic pulse speed and the compressive strength of concrete, with an overall error range of (−12.6%, +5.8%).

However, Yousry et al. [36] also investigated the prediction of compressive strength based on ultrasonic pulse velocity in concrete containing FA produced with MTMW. Their results did not demonstrate a clear trend that could be formulated into a regular equation, unlike normal concrete. Therefore, further studies are needed to elucidate the effect of magnetic treatment on the propagation of ultrasonic pulse waves through concrete prepared with this type of water.

### 5.2.2. Thermo-gravimetric analysis

Malathy [25] conducted a study to investigate the thermal behavior of powder concrete prepared with RW and magnetically treated water. Thermo-gravimetric analysis (ATG) was used to analyze the hydration reaction products. The RW was exposed to a magnetic field intensity of 0.9 T for one hour. The study utilized ATG to examine powder samples from 28-day hardened specimens of normal powder concrete (NPC) and magnetic powder concrete (MPC), which were heated up to 900°C at a rate of 20°C/min.

The results of the study demonstrated that (NPC) specimens exhibited a mass drop of 4.31% compared to (MPC) specimens, which had a mass drop of 2.56%. The authors attributed this trend to the higher cohesion between (MPC) grains compared to (NPC) grains. Consequently, the magnetic treatment provided the water molecules higher energy to deeply penetrate into the cement grains, improving the effectiveness of the hydration reaction and enhancing the mechanical performance of cement-based materials.

## 5.3. Hardened behavior

Numerous studies have investigated the impact of MTMW on the mechanical behavior of cement composites, including compressive strength, tensile strength, and flexural strength. The data obtained from these studies confirmed the positive effect of MTMW on the mechanical properties of cement-based materials.

### 5.3.1. Compressive strength

Numerous investigations have explored the mechanical strength of cement-based materials produced by mixing water subjected to magnetic treatment. These studies have reported that magnetic composites exhibit higher compressive strength, tensile strength, and flexural strength compared to control composites made with regular water [25, 34, 36, 37, 44, 59]. Al-Safy et al. [37] developed two types of cement-based adhesive MCBA using MTMW for mixing and curing specimens. The MTMW was exposed to two magnetic strengths of 9000 and 6000 G, with varying water circulation times. The results indicated that the MCBA samples had the maximum strength with a flow rate of 0.1 m<sup>3</sup>/hr for 15 minutes of circulation time. Another investigation by Yousry et al. [36] showed that the MTMW passing 150 times through the SMF increased compressive strength by 10%, 25%, and 43% after 7, 28, and 56 days, respectively, compared to concretes prepared with tap water. These findings indicated that cement-based composites prepared by the MTMW had higher early age compressive strength than the control composite. Furthermore, Malathy et al. [25] conducted an important research study to assess the

Table 1. Effect of MTMW on compressive strength of cement-based materials

References	Increase (+) or decrease (–) in compressive strength at 28 days (%)
Al-Safy et al. [37]	+0.05 to +22.47
Yousry et al. [36]	+60 at 56 days age
Abdel-Raouf et al. [34]	–26
Malathy et al. [25]	+24.1
Keshta et al. [59]	+23
Ahmed et al. [44]	+80

mechanical behavior of concrete made with regular water exposed to a permanent magnet of 0.9 T at different exposure periods, i.e., 60 min (MW60), 45 min (MW45), 30 min (MW30), and 15 min (MW15). They observed that the MTMW moderately improved the compressive strength with the increase in exposure time. In fact, the compressive strength of MW60 composite improved by 24.1% compared to normal water concrete. Other findings [59, 62, 63] reported that magnetic treatment increased mechanical strength by 10% to 20%. The authors attributed this behavior to the magnetic treatment that provided more energy to water molecules to penetrate more deeply into the cement grains. This behavior activated the hydration reaction and improved the mechanical strength of concrete. However, another study conducted by Abdel-Raouf et al. [34] revealed that the 28-day compressive strength of concrete produced by MTMW subjected to 0.4 T decreased by 26% compared to composite prepared with tap water. The authors explained this trend by the low intensity of the SMF used in this study. Table 1 summarizes the studies mentioned above.

### 5.3.2. Tensile and flexural strength

Karthik et al. [28], observed that using magnetically treated water improved the tensile strength of self-compacting concrete composites containing micro steel fibers, metakaolin, and superplasticizer by 5% as compared to concrete produced with regular drinking water. Another study conducted by Ahmed et al. [44] confirmed increases in the

Table 2. Effect of MTMW on splitting tensile and flexural strength of cement-based materials

References	Increase in splitting tensile strength (%)	Increase in flexural strength (%)
Keshta et al. [59]	20	24
Ahmed et al. [44]	98	22
Sevim et al. [38]	44	–
Karthik et al. [28]	5	–
Zhao et al. [43]	–	31
Reddy et al. [15]	18	15
Salehi et al. [64]	9	–

tensile and flexural strength of silica fume concrete composites by 98% and 22%, respectively, when prepared with MTMW. In addition, Zhao et al. [43] conducted a recent investigation exploring the magnetic field impact on regular water. They prepared the MTMW with four SMF intensities (280, 450, 650, and 800 mT) and five velocities (0.4, 0.6, 0.7, 0.9, and 1.0 m/s). Their results revealed that the MTMW significantly improved the flexural strength of cement-based materials by 31%, with the maximum strength values being obtained at 280 mT. The mechanical performance of the concrete remained consistent even when the cement dosage was reduced. Other studies [15, 38, 64, 65] have confirmed these findings. However, further research [34, 37] found that the MTMW had no effect on the flexural strength of concrete and mortar composites. Table 2 summarizes the studies cited above.

## 6. Durability of cement-based materials prepared with the MTMW

### 6.1. Acid attack

Several studies have examined the durability of cement-based materials mixed with the MTMW and subjected to acid attack solutions [34, 39, 67]. Ghorbani [67] produced concrete block paver samples using normal water (NW) and MTMW exposed to a magnetic field intensity of 0.65 T for different durations (0, 10, 20, 40, and 80 times). All samples were exposed to a 5% H<sub>2</sub>SO<sub>4</sub> solution for 120 days. Their results showed that

the samples produced with MTMW had greater resistance to sulfuric acid attack compared to those produced with NW. The compressive losses were 23% and 34% for MTMW and NW, respectively. Furthermore, the study found that the specimens prepared with MTMW passed 10 times had the highest resistance to sulfuric acid attack compared to other exposures. Moreover, Abdel Raouf et al. [34] also conducted a study on the resistance of concrete produced with the MTMW subjected to a magnesium sulfuric acid attack solution at 10%. All concrete specimens were subjected to weekly cycles of wetting and drying for 8 weeks. Their results indicated that the concrete produced with normal water had an 8% mass reduction, whereas the composites mixing with the MTMW had a 1.2% mass reduction. The specimens exposed to magnesium sulfates exhibited a similar mass reduction regardless of their magnetic field intensity. Additionally, Ahmed [39] confirmed that magnetic concrete incorporating Egyptian nano-alumina had a denser microstructure compared to the same concrete prepared with tap water. The study attributed this trend to the fact that the concrete specimens produced with the MTMW had fewer pores, a higher degree of hydration, and denser microstructures compared to specimens prepared with the NW.

## 6.2. Water absorption

Gholhaki et al. [66] conducted a study on the engineering properties of self-compacting concrete (SCC) produced with MTMW, FA, metakaolin, rice husk ash, and SF. The water absorption test was conducted at the age of 28 days. The results showed that the use of MTMW and pozzolanic materials in SCC reduced water absorption by approximately 55%. Additionally, MTMW reduced the amount of high-range water reducer required for self-compacting concrete by about 45%. Other studies [15, 30] investigated the water absorption of concrete composites produced with MTMW and tap water. They found that the water absorption of magnetized concrete decreased by about 32% compared to that of ordinary concrete. Authors attributed this behavior to the activation

of the cement matrix hydration reaction by the MTMW, which reduced the pore network of the concrete specimens. However, Ghorbani et al. [68] concluded that magnetic treatment had a slight effect on the water absorption of foam concrete. So, magnetic treatment could improve the durability of cement-based materials.

## 6.3. Water permeability

Wang et al. [45] conducted an investigation to evaluate the effect of mixing water subjected to different magnetic field intensities (0.23, 0.28, 0.33 T) and water flow rates (1 m/s, 2 m/s) on the water permeability of concrete (C20, C25, and C30) under a water pressure of 25 bar for 24 hours. The authors revealed that the depth of penetration of magnetic concrete was less than that of ordinary concrete made with regular water. Additionally, the optimum magnetic field that produced the lowest depth penetration was 0.33 T with a water flow velocity of 1 m/s. In contrast, Abdel-Raouf et al. [34] mixed concrete with the MTMW subjected to magnetic field strengths of 0, 0.1, 0.2, 0.3, and 0.4 T and conducted a water-permeability test by applying a pressure of 30 bars for 24 hours. Their results indicated that the magnetic treatment of water had only a slight effect on the water permeability of concrete specimens.

## 7. Effect of MTMW on the concrete's microstructure

Several studies have investigated the microstructure of cement materials produced with MTMW. These studies aim to understand the effects of magnetic treatment on the cement matrix and its potential implications for cement-based materials performance.

One study by Ahmed et al. [44] examined the microstructure of SF concrete prepared with magnetically treated water. The researchers found that magnetic treatment resulted in a more refined and homogeneous microstructure compared to concrete prepared with regular tap water. They observed a denser packing of cement particles, reduced

porosity, and improved interfacial transition zone between the cement matrix and aggregates. These changes in microstructure were attributed to the alignment of magnetic particles and enhanced particle dispersion, leading to improved hydration and inter-particle bonding.

Another study by Ghorbani et al. [65, 67, 68] investigated the impact of magnetic treatment on the microstructure of cement composites. The researchers observed that magnetically treated water led to a more uniform distribution of hydration products within the cement matrix. They also found reduced voids and an improved interfacial transition zone, resulting in enhanced mechanical properties such as compressive strength and flexural strength. The improved microstructure was attributed to the increased nucleation and growth of hydration products, facilitated by the magnetic field.

Furthermore, a study by Bharath et al. [48] focused on the microstructural changes in cement composites produced with magnetically treated water. They observed that MTMW composites have more C-S-H crystals than ordinary composites. They also found that magnetic treatment led to a more compact and uniform distribution of hydration products, resulting in increased mechanical strength and durability of the composites. The improved microstructure was attributed to the magnetic field's influence on the hydration process and the formation of a denser and more interconnected network of hydration products. Many other studies have also confirmed the same effect of MTMW on the hydration products of cement composites [26, 38, 39, 66].

These studies collectively suggest that magnetic treatment of mixing water can significantly influence the microstructure of cement materials. The alignment of magnetic particles and improved dispersion lead to a more refined and homogeneous microstructure, with reduced porosity, improved interfacial transition zone, and enhanced mechanical properties. These findings highlight the potential of magnetic treatment as a technique to optimize the microstructural characteristics of cement materials, ultimately contributing to their improved performance and durability.

## 8. Practical applications, challenges, and the limitations of magnetic activation

In this section, I have examined the practical applications of MTMW in the construction industry. I have also analyzed the feasibility, cost-effectiveness, and scalability of implementing magnetic treatment techniques in real-world situations. Additionally, I have discussed the challenges and limitations that may arise when using this technique. Magnetic treatment has shown potential practical applications in the construction industry, offering an innovative approach to improve the consistency, strength, and durability of cement-based materials. This can lead to the development of more robust and sustainable structures.

Achieving good consistency in concrete produced with MTMW offers substantial practical applications in the construction industry. It improves workability and ease of placement, reducing the risk of segregation or bleeding and increasing productivity onsite. It also enhances the quality and durability of structures by minimizing defects and strengthening the concrete. In pre-cast concrete production, good consistency ensures precise mixtures, improving strength and dimensional accuracy. Magnetized concrete with good consistency can also contribute to sustainability by optimizing mix design and reducing water content. Overall, achieving good consistency in magnetized concrete brings significant positive impacts to construction projects [9, 18, 21, 69, 70].

The practical application of achieving high mechanical strength in concrete using magnetically treated mixing water offers several benefits in the construction industry. It is useful for constructing high-rise MTMW buildings and heavy-duty structures, improving load-bearing capacity and structural integrity. It is also beneficial for infrastructure projects, providing resistance to cracking, durability, and corrosion resistance. The high mechanical strength is advantageous for rapid construction and early load-bearing needs. Additionally, it can lead to cost savings by reducing maintenance and repairs [9, 18, 21, 69, 70]. Figures 3, 4, and 5 show a few practical examples



Cement slab produced with regular water

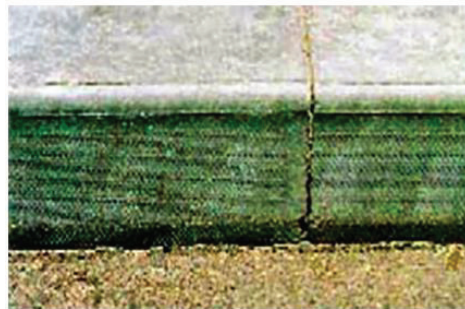


Cement slab produced with MTMW

Fig. 3. Cement slabs on highway exposed to a wide range of temperature changes (summer up to 40°C, winter down to -40°C) after one year [69]



Concrete produced with regular water



Concrete produced with MTMW

Fig. 4. Highway precast pavement after three years [69]



Pavement produced with regular water



Pavement produced with MTMW

Fig. 5. Change in the cement pavement after five years [69]

showcasing the impact of magnetic activation on the longevity of cement materials produced using magnetized water. The images provided illustrate a comparison between the durability of

concrete created with regular water and magnetized water. These studies unequivocally demonstrate the superior durability of magnetized concrete when compared to regular concrete. These findings are

consistent with the conclusive evidence presented in the earlier sections, particularly the section on durability.

Implementing magnetic treatment techniques in real-world scenarios requires careful consideration of feasibility, cost-effectiveness, and scalability. Feasibility depends on the availability of suitable equipment and the compatibility of materials with magnetic fields. The construction industry would need to invest in specialized equipment, such as magnetic mixers, to effectively implement this technique. The cost-effectiveness of magnetic treatment should be evaluated by comparing the potential benefits, such as improved mechanical properties and reduced maintenance, with the initial investment and operational costs. The scalability of magnetic treatment techniques is crucial for their widespread adoption. It is important to assess whether the techniques can be efficiently applied in large-scale construction projects without compromising quality or increasing costs significantly. Additionally, the compatibility of magnetic treatment with different types of construction materials should be considered to ensure its applicability across various projects. Overall, feasibility, cost-effectiveness, and scalability are essential factors to evaluate when considering the implementation of magnetic treatment techniques in real-world scenarios [9, 18, 21, 69, 70].

The use of MTMW in concrete technology has great potential, but it also comes with challenges and limitations. One challenge is the need for precise control of the magnetic field intensity and exposure time. If not properly controlled, inconsistent results can occur, and the desired mechanical properties of the concrete may be compromised. Another challenge is the requirement for specialized equipment and infrastructure to implement the magnetic treatment process. This can add extra costs and logistical considerations for construction companies. Although successful in laboratory settings, the effectiveness and efficiency of this technology in large-scale construction projects still need to be proven. One limitation of magnetic treatment is that the magnetic effect gradually diminishes after treatment, and the exact duration for complete loss of this effect is still uncertain.

This means that the beneficial properties induced by magnetic treatment may decrease over time, potentially affecting the long-term durability and performance of the concrete. Further research is necessary to fully understand the longevity of the magnetic effect and its impact on the effectiveness of this technology [9, 18, 21, 69, 70].

## 9. Conclusion

This review study aimed to investigate the influence of magnetically treated mixing water on the behavior of cement-based materials. After a comprehensive review of relevant studies, the following recommendations can be made:

- The properties of MTMW are influenced by four key parameters: distance between poles, magnetic field intensity, speed of flow, and exposure time. The optimal effect of magnetic treatment has been observed with a magnetic field intensity ranging from 0.4 to 1.2 T and an exposure time of 24 hours. It is important to note, however, that the magnetic effect gradually diminishes after magnetic treatment, and the exact duration before complete loss of this effect is still uncertain.
- When water molecules are exposed to a magnetic field, they align in a single direction and become smaller in size compared to regular water. Moreover, magnetically treated water demonstrates lower surface tension, viscosity, and boiling point compared to regular water. Additionally, researchers have observed that minerals and acids are more soluble in magnetically treated water. This has led many researchers to believe that it can enhance the properties of cement-based materials by facilitating the hydration reaction with Portland cement. However, further research is necessary to clarify the exact interactions between magnetic water and cement during chemical reactions.
- In terms of the fresh properties of cement-based composites produced with MTMW,

most studies have consistently reported improvements in workability. These improvements are attributed to a reduction in viscosity, resulting in increased plasticity even with a lower amount of mixing water. Additionally, research has shown that the use of MTMW reduces the need for plasticizers in concrete mixtures. Furthermore, cement-based materials prepared with MTMW exhibit significant reductions in both the initial and final setting times.

- Several reviewed studies have consistently shown significant enhancements in the compressive, tensile, and flexural strength of cement-based materials produced with MTMW. In particular, these composites exhibited substantial increases in strength compared to those prepared with regular water. Researchers attributed these improvements to the magnetic treatment of water molecules, which allows for deeper penetration into the cement grains and enhances the hydration reaction. It is worth noting, however, that some research papers have reported even higher improvements of up to 98% in the mechanical behavior of cement-based materials with MTMW. These results may require further investigations and more comprehensive studies to provide convincing explanations and confirm their validity.
- In terms of microstructure, the studies reviewed consistently demonstrate that magnetic treatment has a positive impact. It leads to a more refined and homogeneous microstructure, characterized by denser packing of cement particles, reduced porosity, and improved interfacial transition zones. Additionally, magnetically treated water promotes a more uniform distribution of hydration products, resulting in the formation of more C-S-H crystals and a denser, interconnected network of hydration products in cement-based composites. These findings collectively emphasize the potential of magnetic treatment as a technique to

optimize the microstructural characteristics of cement-based materials, ultimately enhancing their mechanical performance and durability.

In general, magnetic treatment of mixing water has a significant impact and positive effects on the behavior and performance of cement-based materials. However, previous studies have not explored the influence of magnetically treated mixing water on the durability of cement-based materials in relation to freeze/thaw cycles, carbonation, deicing salts, and the alkali-silica reaction. Therefore, my intention is to conduct a study specifically focusing on these areas. Additionally, I will also investigate the effects of magnetically treated water on the fresh, hardening, and durability properties of cement-based materials incorporating reused rubber aggregates. These materials often experience a decline in their fresh and mechanical performance. I believe that utilizing magnetically treated mixing water has the potential to address some of the challenges associated with cement-based composites containing reused rubber aggregates.

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