Preparation of Electric- and Magnetic-Activated Water and Its Influence on the Workability and Mechanical Properties of Cement Mortar

Kaiyue Zhao, Peng Zhang, Bing Wang, Yupeng Tian, Shanbin Xue and Yuan Cong

School of Civil Engineering, Qingdao University of Technology, Qingdao 266033, China; applezky@126.com (K.Z.); bing0221@163.com (B.W.); qdlgtyp@163.com (Y.T.); shanbin_xue@163.com (S.X.); yuan_qut@126.com (Y.C.)

Center for Durability & Sustainability Studies of Shandong Province, Qingdao University of Technology, Qingdao 266033, China

Qingdao Municipal Construction Group, Qingdao 266000, China

Correspondence: peng.zhang@qut.edu.cn

Abstract: Cement-based materials prepared with activated water induced by a magnetic field or electric field represent a possible solution to environmental issues caused by the worldwide utilization of chemical admixtures. In this contribution, electric- and magnetic-activated water have been produced. The workability and mechanical properties of cement mortar prepared with this activated water have been investigated. The results indicate that the pH and absorbance (Abs) values of the water varied as the electric and magnetic field changed, and their values increased significantly, exhibiting improved activity compared with that of the untreated water. In addition, activated water still retains activity within 30 min of the resting time. The fluidity of the cement paste prepared with electric-activated water was significantly larger than that of the untreated paste. However, the level of improvement differed with the worst performance resulting from cement paste prepared with alternating voltage activated water. In terms of mechanical properties, both compressive strength and flexural strength obtained its maximum values at 280 mT with two processing cycles. The compressive strength increased 26% as the curing time increased from 7 days to 28 days and flexural strength increased by 31%. In addition, through the introduction of magnetic-activated water into cement mortar, the mechanical strength can be maintained without losing its workability when the amount of cement is reduced.

Keywords: cement mortar; magnetic field; electric field; activated water; workability; mechanical properties

1. Introduction

Concrete is a widely used material that is adaptable to many purposes, but the usefulness and versatility of concrete as a construction material are due in great deal to the many fields and laboratory investigations performed to analyzes its performance over the past century [1–5]. The significant progress in the improvement of concrete field benefits from the development of chemical admixtures. As an essential component of concrete, various chemical admixtures have been used to improve its performance. Chemical admixtures enable the production and construction of high-performance and ready-mix concrete possible [6].

However, chemical admixtures will inevitably cause environmental pollution problems during the production process, e.g., the waste and exhaust emissions during the production process of water-reducing agents and air-entraining agents, which gradually threaten the environment [7,8]. It has been claimed that environmental issues will play a leading role in the sustainable development of the cement and concrete industry in this century [9]. Incorporation of nano materials in cement-based materials is another method...
to improve its strength and pore structure [10]. From the application point of view, the cost of concrete increases after adding nano materials into it [11]. Moreover, when adding materials to concrete, it is hard to ensure that all materials could uniformly distribute in concrete especially pouring lots of concrete [12].

When water flows through an electric or magnetic field at a stable speed under specific conditions, it becomes activated water and is called electric-activated water or magnetic-activated water. Notably, the magnetization procedure for water treatment is simple without an extra energy consumption when a permanent magnet is used [13]. This green technique is zero energy consumption and clean compared to the aforementioned methods such as incorporation of nano materials or chemical admixtures. Additionally, many researchers have shown that applying magnetic-activated water to concrete mixing can improve the fluidity [14], accelerate the cement hydration reaction [15], increase the compressive strength [16,17], and reduce the corrosion rate of the steel rebars [18]. The utilization of magnetic-activated water instead of regular tap water to produce concrete mixes also reduces the amount of cement used in concrete by about 5% [15,19]. In this way, magnetic-activated water can be utilized to reduce the consumption of cement to produce sustainable concrete [9]. Therefore, cement-based materials prepared with activated water induced by a magnetic field or electric field represent a possible solution to the above issues due to their abundant supply, ease of production, and the characteristics of environmental protection.

The water content in traditional cement-based materials has a remarkable influence on their workability [20–23]. Water is driven off in the cement-manufacturing process, and then chemical changes occur that make the final powder reactive in the presence of water. In this way, it activates the cement-based materials, and “hydration” comes from the fact that water molecules combine with minerals in cement chemically and physically [24]. However, studies regarding water used for cement-based materials have been scarce. It has been theoretically [25] and experimentally [26] reported that electromagnetic exposure leads to structural changes in water. Magnetization increases negative ionic hydration, resulting in the intensification of the damaging effect on the water molecular structure [27,28]. Concrete mixed with magnetic-activated water exhibits a reduction in the adsorption of active surface substances at the interface between water and cement, allowing an acceleration of the hydration process. The hydration reaction initially occurs on the surface of cement particles, and later a thin layer is formed on the cement particles, acting as a barrier that hinders further hydration of cement particles [29–31]. However, magnetic-activated water can readily penetrate into the cement particles, resulting in a more complete hydration reaction and improving the mechanical performance of cement-based materials [32].

Previously, changes in various physical properties of magnetic-activated water have been reported. An increase of the water viscosity [33], Abs values, and pH values [34], and decrease of water surface tension [32] owing to a magnetic field has been observed. More recently, studies on the physical, mechanical, and microstructural performance of cement pastes subjected to static magnetic fields has been carried out [35]. The results suggested that in the case of higher magnet-ostatic induction strengths, e.g., 25.37 Gauss, the amount of calcium silicate hydrate gel is larger, and its morphology becomes denser and less porous. This is consistent with a previous work [36] on a hydrated cement paste prepared with mechanically activated water, which declared a modification of the porous structure of cement paste. Later, five mix proportions of concrete blocks were prepared with magnetic-activated water that passed through a magnetic field 10, 20, 40, and 80 times at a constant speed of 2.25 m/s to investigate the effect of magnetized water on the mechanical properties of concrete specimens. The results indicated that the average improvements compared to the control mix were 12.5% in compressive strength, 13% in splitting tensile strength, and 9% in flexural strength. [37]. Moreover, their SEM images of specimens prepared with magnetized water instead of tap water exhibited an improved microstructure, resulting in a denser structure [37]. Meanwhile, the engineering properties
of self-compacting concrete incorporating magnetic water and pozzolanic materials have been evaluated \cite{38,39}, and the results indicated that adding magnetic water and pozzolanic materials into cement-based materials can improve the self-compatibility criteria in terms of flowability and viscosity. Moreover, as previously mentioned, activated water does not require the addition of chemical admixtures, thereby avoiding environmental pollution.

Recently, attempts have been made to produce activated water through an electric field. The properties of cement-based materials prepared with electric-activated water have gradually been reported. Studies have shown that applying electric-activated water to concrete mixing can produce more hydration heat, increase its fluidity, and enhance its compressive strength \cite{40}. However, present studies are mainly focused on magnetic-activated water and its corresponding properties, whereas the method of activating water with an electric field, especially for a high-voltage field and alternating voltage field, is rarely observed. In addition, the method of preparing activated water and its influence on the workability and mechanical properties lacks a comprehensive understanding. To better understand the above issues, we made an attempt to study the physical properties of electric- and magnetic-activated water. Then, the workability and mechanical properties of cement-based materials prepared with this activated water were investigated.

2. Materials and Methods

2.1. Raw Materials

The chemical compositions and particle size distribution of ordinary Portland cement (OPC) can be seen in Table 1 and Figure 1, respectively. The standard sand used to make the mortar samples meets the requirements of GB/T17671-1999. The water used in this project includes tap water and distilled water.

| SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | SO$_3$ | K$_2$O | Na$_2$O | TiO$_2$ | P$_2$O$_5$ | LOI |
|--------|-------------|-------------|------|-----|--------|-------|--------|---------|----------|-----|
| 19.44  | 7.55        | 5.36        | 57.32| 4.32| 3.30   | 0.94  | 0.21   | 0.50    | 0.31     | 2.72 |

Table 1. Chemical compositions of OPC.

Figure 1. Particle size distribution of OPC.

2.2. Electric Field Activated Device

2.2.1. High-Voltage Field

The high-voltage field-activated device consists of 4 parts: a high-voltage electrostatic generator, a high-voltage output line, a water pump, and a water treatment chamber, as shown in Figure 2. Four voltages of 1000, 1500, 2000, and 2400 V were designed to prepare the activated water. The centers of the positive and negative charges do not coincide due to the polarity of the water molecule. As a result, under the effect of the high voltage field, the hydrogen atoms located at the positive charge center of the water molecules move towards the cathode, while the oxygen atoms located at the negative charge center
move towards the opposite direction. The opposite forces applied on the hydrogen atoms and oxygen atoms lead to the decomposition of the larger molecular clusters into small molecular clusters, which enhances the activity of the water [41,42]. It is worth noting that the asymmetric structure of the water inlet and outlet of the device was designed to produce fully activated water. Experiments were conducted to investigate the physical properties of activated water and the fluidity of the cement paste prepared with activated water.

2.2.2. High-Frequency Field

The high-frequency field-activated device consists of 4 parts: a high-frequency signal generator, an output line, a water pump, and a water treatment chamber, as shown in Figure 3. Two frequency signals of 10 and 15 MHz were designed to prepare the activated water. The output frequency of the high-frequency signal generator is close to the natural frequency of the structure of the water molecule cluster in the cavity, resulting in the generation of a resonance. The larger molecular clusters then absorb a large amount of energy, which strengthens the thermal motion of the water molecules, and thus the hydrogen bonds between the molecules are broken, increasing the activity of the water. Experiments were conducted to investigate the physical properties of activated water and the fluidity of cement paste prepared with activated water.

2.2.3. Alternating Voltage Field

The alternating voltage field-activated device is composed of an alternating power source, a water pump, and a water treatment chamber that is identical to the treatment chamber in the high-frequency field-activated device. Three alternating voltages of 10, 15, and 20 V were designed to prepare the activated water. Experiments were performed to investigate the physical properties of activated water and the fluidity of cement paste prepared with activated water.
2.3. Magnetic Field Activated Device

Generally, a water molecular group contains approximately 100 water molecules at room temperature [43], but when water flows through a magnetic field, they are then affected by the Lorentz force, resulting in hydrogen bonds breaking, producing small water molecules or single water molecules. In other words, water passing through the magnetic field-activated device at a certain flow rate will be magnetized and become highly activated water molecules [44].

The magnetic field-activated device is mainly composed of a constant flow pump and a water treatment chamber that contains a certain number of magnets, as shown in Figure 4. Four magnetic field intensities of 280, 450, 650, and 800 mT with 5 water current velocities of 0.4, 0.6, 0.7, 0.9, and 1.0 m/s were applied to prepare the activated water. Experiments were performed to investigate the physical properties of activated water and the fluidity and engineering properties of cement-based materials prepared with activated water.

![Magnetic field-activated device](image)

**Figure 4.** Magnetic field-activated device: (a) schematic diagram and (b) experimental apparatus.

2.4. Measurement of the Physical Properties of Water

The change in the pH value was tested with a pH meter. The pH meter was first standardized and then rinsed with distilled water before measuring the values of the activated water. Meanwhile, the absorbance (Abs) of the activated water in the ultraviolet region was measured with a visible UV spectrophotometer, with scanning wavelengths ranging from 190 to 330 nm. It should be noted that Abs is a number that measures the attenuation of the transmitted radiant power in a material. The Abs value and pH value are adopted in the text to reflect the changes of physical properties in water when it was activated by an electric field or by a magnetic field.

2.5. Measurement of the Workability of Cement Paste

Cement paste, with a water to cement ratio of 0.41, was adopted in the test. The fresh mixture was poured into the truncated cone mold, and then the crossest method was utilized to measure the 2 longest mutually perpendicular diameters after the mold was moved away, as shown in Figure 5. The average value of the aforementioned 2 diameters was taken as the final fluidity of the cement paste. The determination of fluidity followed the requirements of GB/T 8077-2012.

![Measurement of fluidity](image)

**Figure 5.** Measurement of the fluidity of cement paste.
3. Results and Discussion
3.1. Physical Properties of Water
3.1.1. Water in a Natural State

Water molecules are composed of two hydrogen atoms and one oxygen atom that are connected in the form of covalent bonds, forming an isosceles triangle structure, as shown in Figure 6a. For the oxygen atom nucleus, there are two inside electrons that reach a stable state and six outside electrons with an unstable state, while for the hydrogen atom nucleus, there is only an electron outside the nucleus, resulting in 10 electrons outside the core of a water molecule, which forms four electron orbitals, as shown in Figure 6b. Additionally, the electronegativity ratio of the oxygen and hydrogen atoms in water molecules is 8/2; thus, the density of the electron clouds near the hydrogen atoms is much smaller than that near around the oxygen atoms. The positive and negative charge centers of the water molecule do not coincide due to the existence of the aforementioned electronic structure, resulting in the strong polarity of the water molecule. The Van der Waals force and hydrogen bonds are then generated by the strong polarity of the water molecules, leading to the formation water clusters.

![Figure 6. Illustration of water molecule structure (a) and extranuclear electron distribution (b).](image)

The formation of hydrogen bonds is an important feature of water molecules, during which a highly negative oxygen atom can attract the positively charged hydrogen atom nearby through an electrostatic interaction along the arc pair of the electron orbits. A hydrogen bond is then formed, as shown in Figure 7. In contrast to covalent and ionic bond, hydrogen bonds are much weaker, with longer bond lengths and lower bond energies of approximately 2–8 kcal. However, the energy of hydrogen bonds, though smaller than that of the covalent and ionic bonds, is larger than the intermolecular force.

![Figure 7. Hydrogen bond of the water molecules.](image)

Due to the existence of hydrogen bonds, a single water molecule with a lighter mass can be attracted to become a larger bound water molecule, which forms so-called water clusters. The water molecules tend to develop in the direction of generating more hydrogen bonds, since in this state, the polarity of the water clusters decreases and tends to be neutral. Therefore, the natural state of water exists in the form of water molecular clusters instead of a single water molecule.
However, the large water molecular clusters can be broken into smaller ones if a certain amount of energy is transferred to the large clusters. Unlike water with larger water molecular clusters, the physical properties of water with smaller clusters are changed [33]. Moreover, water with smaller water molecular clusters gives rise to many phenomena, such as an enhancement in the compressive strength of concrete and in the precipitation process of calcium carbonate [16,45], as well as a reduction of the corrosion rate of steel rebar [18]. Therefore, attempts have been made to break the hydrogen bonds between water molecules by the application of electric fields, magnetic fields, laser methods, and ultrasound methods. The schematic of effect of electric or magnetic field on water molecule clusters can be seen in Figure 8.

Figure 8. Schematic of effect of electric or magnetic field on water molecule clusters.

3.1.2. Influence of the Electric Field

Water tends to contain a larger molecular water clusters in a natural state; however, as mentioned earlier, the hydrogen bonds may change due to the application of an electric field, resulting in the change in its properties. Meanwhile, there exists a “time effect” for activated water, or in other words, after the water is activated by electric field or magnetic field, its related physical properties have changed, and this change can maintain some period of time before the activated water finally returns to its initial un-activated state. It is of great importance to understand how the electric field affects the properties of water and whether its activity can retain. Therefore, we studied the influence of the electric field, which includes a high-voltage field, high-frequency field, and alternating voltage field, on the physical properties of electric-activated water, immediately and after 30 min of resting time. It should be noticed that untreated water refers to the water activated by a high-voltage field for 0 min. Typical results for the influence of a high-voltage field on the changes in the pH and Abs values of electric-activated water can be seen in Figures 9 and 10, respectively.

Figure 9. pH value change of electric-activated water with different high voltages: (a) initial values and (b) values after resting for 30 min.
Figure 10. Abs value change of electric-activated water with different high voltages: (a) initial values and (b) values after resting for 30 min.

High voltage has a significant influence on the pH values of activated water, with the most obvious change resulting from water treated with a high voltage of 2400 V. In addition, the pH values of the activated water after resting for 30 min have a small fluctuation and basically maintain the same trend compared with the initial value, indicating that the activated water after resting for 30 min still retains activity. This phenomenon had also been mentioned in an earlier publication [46]. The combination of perturbations of the gas liquid surface and the production of reactive oxygen species may account for this phenomenon [47]. As a whole, the increased pH values of activated water indicate that the activity is improved compared to that of the untreated water. This improved activity may arise from the decomposition of larger water molecular clusters into smaller clusters or single water molecular clusters, which changes the ion product constant of water, thereby improving the solubility of the solution.

Regardless of the high voltage values, the Abs of high-voltage field-activated water in the ultraviolet wavelength range of 190–240 nm was significantly higher than that of water in the natural state, also exhibiting improved activity, and the difference was more prominent with longer wavelengths. Water treated with all values of high voltages reached its maximum value at a wavelength of 195 nm. Meanwhile, the Abs values after resting for 30 min remained almost the same as the initial values.

The influence of the high-frequency field on the physical properties, including the pH and Abs values, of electric-activated water was considered, with the results clearly shown in Figures 11 and 12, respectively. It should be noticed that untreated water refers to the water activated by a high frequency field for 0 min. Although the water samples were treated with different high frequency signals, they all exhibited a similar increasing trend, suggesting that the high frequency had a remarkable influence on the pH values and that the water activity had been improved. However, the pH values of water treated with a high-frequency signal of 15 MHz were significantly larger than those treated with 10 MHz. Meanwhile, water can still retain its activity after resting for 30 min when it was treated with a high-frequency field after resting for 30 min. As mentioned earlier, the larger molecular clusters absorb a large amount of energy created by the resonance between the high frequency signals and water molecules, leading to strengthened thermal motion of the water molecules, and thus the hydrogen bonds between the molecules are broken, which increases the solubility of the solution and finally enhances the pH values.
Similar to the water treated with high voltages, water treated with a high-frequency field in the ultraviolet wavelength range of 190–240 nm was significantly higher than that of water in the natural state, which indicated that the water activity was improved. Water samples treated with all values of the high frequency signals reached their maximum values at a wavelength of 195 nm. When the wavelength is larger than 195 nm, the Abs values drops rapidly. The Abs values of the water treated with a high frequency field of 15 MHz was larger than that of the water treated with 10 MHz. Water can still retain its activity after resting for 30 min when it was treated with a high frequency field.

The influence of the alternating voltage field on the physical properties, including the pH and Abs, of water activated by the alternating voltage is shown in Figures 13 and 14, respectively. It should be noticed that untreated water refers to the water activated by an alternating voltage field for 0 min. It can be seen that the pH values of the water treated with alternating voltages were higher than that of the untreated water, regardless of how the alternating voltages changed, also exhibiting improved water activity. In addition, the pH values of the activated water were almost the same when the treatment time was

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**Figure 11.** pH value change of electric-activated water with different high frequency fields: (a) initial values and (b) values after resting for 30 min.

**Figure 12.** Abs value change of electric-activated water with different high-frequency fields: (a) initial values and (b) values after resting for 30 min.
shorter than 5 min, while the pH values increased quickly when the treatment time was longer than 5 min, with the highest pH value resulting from water treated for 20 min with an alternating voltage of 15 V.

![Figure 13. pH value change of electric-activated water with different alternating voltages.](image1)

Regardless of how the alternating voltages changed, the Abs of activated water was higher than that of untreated water, which suggests that the water activity was improved. The Abs values of the activated water with different alternating voltages all reached their maximum values when the wavelength was 195 nm. However, when the wavelength was greater than 195 nm, the Abs of the activated water dropped sharply to 210 nm, and then basically became stable. In addition, the Abs values increased as the treatment time extended, with the highest Abs value resulting from water treated for 20 min with an alternating voltage of 15 V.

![Figure 14. Abs value change of electric-activated water with different alternating voltages.](image2)

3.1.3. Influence of the Magnetic Field

Extensive studies had suggested that the properties of water are changed when it flows through a magnetic field [14,15,32,48]. It is of interest to know how the magnetic field affects the properties of water. Therefore, we studied the influence of a magnetic...
field on the physical properties of magnetic-activated water, including the pH and Abs. Typical results of the influence of the magnetic field on the pH and Abs value change of magnetic-activated water can be seen in Figure 15. It should be noticed that untreated water refers to water treated by a magnetic field with current velocity of 0 m/s and processing cycles of 0.

![Figure 15. Physical properties of magnetic-activated water under the influence of a magnetic field: (a) pH values and (b) Abs values.](image)

Obviously, the current velocity and magnetic field intensity both have a remarkable influence on the change in the pH values. The largest pH value results from water treated with a magnetic field intensity of 650 mT and a current velocity of 0.4 m/s. The reason for the enhancement in the pH values may have been that the magnetic field affects the ion product constant of water, which then affects the dissociation of the aqueous solution and raises the pH values as a result [32,49]. As for the Abs values, a magnetic field intensity of 650 mT was adopted since the improved pH value was observed in this case. It can be clearly seen that the activated water had an increased Abs value compared with the untreated water in the ultraviolet region, suggesting that the water activity was improved. Meanwhile, the effect of processing cycles cannot be ignored with the highest Abs value coming from magnetic-activated water with 30 processing cycles at 195 nm. This phenomenon may be attributed to the action of atoms, electrons, and molecules in the water molecules due to the magnetic field, which leads to the breakage of the hydrogen bonds between the water molecules, thus causing the decomposition of large water clusters into small water clusters, resulting in improved activity of the water.

### 3.2. Workability of Cement Paste

#### 3.2.1. Prepared with Electric-Activated Water

The workability of concrete is defined in ASTM C 125 as the property that determines the effort required to manipulate freshly mixed concrete with a minimum loss of uniformity. The importance of workability in concrete technology is apparent [50]. It is one of the key properties that must be satisfied. Regardless of the sophistication of the mix design or cost, concrete mixtures that cannot be easily placed or fully compacted are unlikely to yield the expected strength and durability performance [51]. It is possible to modify the workability of cement paste by the introduction of electric-activated water. Hence, the influence of electric fields, including a high-voltage field, high-frequency field, and alternating voltage field, on the workability of cement paste prepared with electric-activated water were studied. It is worth noting that a high voltage of 2400 V, high frequency of 15 MHz, and alternating voltage of 15 V were adopted here since it is under these cases that the treated water exhibited enhanced physical properties. The typical results are shown in Figure 16.
Figure 16. The fluidity of cement paste prepared with electric-activated water: (a) high voltage of 2400 V, (b) high frequency of 15 MHz, and (c) alternating voltage of 15 V.

In the case of cement paste prepared with high-voltage-treated water, as seen from Figure 16a, the fluidity of the cement paste showed an increasing then decreasing trend as the processing time increased, where the best fluidity performance of 126.68 mm can be seen in samples treated for 60 min. This improved fluidity could be attributed the opposite forces applied on the hydrogen atoms and oxygen atoms through the high voltage of 2400 V, which leads to the decomposition of the large molecular clusters. Consequently, the water molecules can be arranged closer together and the density increases, resulting in an increase of the buoyancy of activated water [42,43]. This can improve the dispersion of the solid phase during hydration reaction, allowing cement particles uniformly dispersed in the water, increasing hydration reaction products and thus promoting the formation of a thicker and more stable C–S–H hydration film on the surface of the cement slurry at the beginning of the hydration process. This particular film weakens not only the friction between the particles but also the flow of the network structure. In this way, good workability was acquired.

Similar to the trend occurring in the fluidity of cement paste prepared with high-frequency field-induced water, in Figure 16b, the best fluidity performance of cement paste prepared with high-frequency field-induced water was expected in samples treated for 30 min, and the value was 124.48 mm. However, when the water was treated more than 60 min, the fluidity of activated water mixed samples was lower than that of the samples prepared with tap water. This improved fluidity arose from the fact that the output frequency of the high-frequency signal generator is close to the natural frequency of the structure of the water molecule cluster, allowing for the generation of a resonance. The larger molecular clusters then absorb energy, strengthening the thermal motion, and thus the hydrogen bonds between the molecules are broken, increasing the activity of the water. Therefore, the specimens prepared with high-frequency-activated water exhibited better fluidity than normal tap water.

Different from the cases of the high-voltage field and high-frequency field, the fluidity performance of cement paste prepared with alternating voltage treated water did not significantly change as the processing time increased, and the best fluidity of 106.62 mm was observed in samples treated for 15 min, as shown in Figure 16c. Additionally, the fluidity of cement paste prepared with alternating voltage activated water was obviously smaller than that of the aforementioned two cases.

3.2.2. Prepared with Magnetic-Activated Water

Meanwhile, it is also possible to modify the workability of cement paste by the introduction of magnetic-activated water. Figure 17 shows the fluidity of cement paste prepared with magnetic-activated water under the influence of the magnetic field intensity and current velocity.
The fluidity of cement paste prepared with magnetic-activated water under the influence of (a) the magnetic field intensity and (b) current velocity.

The influence of the magnetic field intensity on the fluidity of cement paste prepared with activated water was complicated, with multiple extremum values being observed at 280 and 450 mT. The first peak value of 111.13 mm appeared at 280 mT with a current velocity of 1 m/s. On the whole, the fluidities of the cement paste mixed with magnetic-activated water were greater than those of the cement paste mixed with untreated water, and they basically exhibited an increasing and then decreasing trend. For the influence of the current velocity on the fluidity of cement paste prepared with activated water, a similar increasing and then decreasing trend of the fluidity was also found here with the increase in the current velocity. This phenomenon may be attributed to the Lorentz force increasing with increasing magnetic field intensity and current velocity, but when the velocity reaches a certain value, water becomes turbulent and stays in the magnetic field for a shorter time, resulting in a reduction in the magnetization effect.

3.3. Mechanical Properties of Cement Mortar

Mechanical strength is defined as the ability of a material to resist the stress generated by an external force without failure [51]. It is a significant material parameter used to characterize cementitious materials, which are porous solids, and simple empirical relationships between the strength and porosity have been found to represent data for a wide range of materials. Instead of conventional methods of incorporating more mineral additions or reducing the water-to-cement ratio to improve the mechanical strength, an attempt is made in this chapter to determine if the introduction of magnetic-activated water could have a positive influence on the mechanical properties of cement mortar prepared with magnetic-activated water.

Cement mortar was prepared by OPC, standard sand, and water, with a proportion of 1:3:0.5 by mass. After standard curing (20 ± 2 °C, 98% RH) for 7 days and 28 days, the mechanical test was performed using a hydraulic pressure testing machine (DY208-M30). Figure 18 shows the compressive strength and flexural strength of mortars prepared with magnetic-activated water with different curing ages. Obviously, both compressive strength and flexural strength obtained its maximum values at 280 mT with two processing cycles. The compressive strength increased 26% at a longer curing time and flexural strength increased 31%. This improvement in mechanical strength can mostly be attributed to the higher hydration degree and more denser pore network of the system at longer curing time. However, activated water also plays a role in the mechanical strength improvement, but is more pronounced in shorter curing time. Compared with specimens prepared with tap water, the compressive strength of activated water mixed system was found with an enhancement of 27% at 7 days and 13% at 28 days. This result is in line with the
literature [14,16]. The improved mechanical strength may largely due to the higher specific area of magnetic water in comparison with the regular tap water. The magnetic-activated water breaks the larger water cluster into small water clusters or single water molecules, which are conducive to the full reaction of cement particles with water. In addition, the hydrogen bonds in water participate in the synthesis of hydration products, enhancing the binding force of hydration products, allowing a dense and fibrous hydrated C–S–H gel to be formed. In this way, a higher hydration degree and more hydration products were expected for specimens prepared with magnetic water, which may lead to the enhancement of mechanical strength. The aforementioned dense structure was observed by Ghorbani et al. [37] in their SEM images, from which they found larger more and more frequent crystals in the specimens mixed with magnetized water compared to the control mix.

![Figure 18. Mechanical strength of mortar prepared with magnetic-activated water with different curing ages under the influence of magnetic field intensity and processing cycles: (a) compressive strength and (b) flexural strength.](image)

Although the content of cement decreased, an improvement in the compressive strength and flexural strength of the cement mortar was observed in samples prepared with water induced by a magnetic field intensity of 280 mT with increasing rates of 3.9% and 5.5%, as shown in Figure 19. Meanwhile, the fluidity of cement mortar prepared with magnetic-activated water remained almost the same when the amount of cement decreased. When cement and water content was reduced compared to the control sample, the sand content remained the same, suggesting a decreased cement to sand ratio. This ratio was correlated to fluidity because that the fluidity values of mortar may be decreased as the cement to sand ratio decreased, due to the fact that the friction of fine aggregates is increased with the reduced amount of cement slurry. The abnormal fluidity values in the current research suggests that magnetic-activated water may play an appositive role in improving the workability of cement mortar. Thus, it is beneficial to study the influence of magnetic-activated water on the mechanical strength of cement mortar by the introduction it into cement mortar, not only reducing material use but also meeting the mechanical strength requirements.
4. Conclusions

The physical properties of electric- and magnetic-activated water and their influence on the workability and mechanical properties of cement mortar were investigated. On the basis of these results, we can draw the following conclusions:

(1) The physical properties of activated water, including the pH and Abs values, varied as the electric and magnetic field changed, and their values increased significantly, exhibiting improved activity compared with that of the untreated water. The pH values with remarkable enhancement came from water treated with a high voltage of 2400 V, high frequency signals of 15 MHz, an alternating voltage of 15 V, and a magnetic field intensity of 650 mT. The obvious improvement in the Abs values were obtained at the wavelengths of 195 nm for the electric field and 190 nm for the magnetic field. In addition, activated water still retains activity within 30 min of the resting time.

(2) The workability of cement paste prepared with activated water could be improved to varying degrees, and the improvement was more prominent for samples with longer curing times. However, the level of improvement differed with the worst performance resulting from cement paste prepared with alternating voltage-activated water. For the fluidity of cement paste prepared with magnetic-activated water, the best performance was observed for water treated with a magnetic intensity of 280 mT coupled with a current velocity of 1.0 m/s.

(3) The mechanical strength of cement mortar prepared with magnetic-activated water can be improved by 27% in compressive strength and 31% in flexural strength as the curing time increased from 7 days to 28 days. They both obtained its maximum values at 280 mT with two processing cycles. In addition, through the introduction of magnetic-activated water into cement mortar, the mechanical strength can be maintained without losing its workability when the amount of cement is reduced.

Since the cleaner production is the norm in industry and technology today and as it is a preventative method of dealing with environmental and economic issues, it must be pointed out that water treatment by electric or magnetic filed is one of the main features of cleaner production aspects because it brings many environmental and economic benefits. However, water treatment by electric or magnetic filed is still a controversial subject as the reported results have low reproducibility and little consistence. In addition, the various factors including magnetic impurites and dissovled ions make the experiment difficult to
control. The presented results may provide some theoretical guidance to the application of activated water on cement-based materials.

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