Effect of Alternating Electromagnetic Activated Water on Properties of Cement Mortar

Zhifeng Zhang 1,*, Borong Li 1,*, Nan Song 1, and Lei Zhao 2,*

1Key Laboratory for Highway Construction Technology and Equipment of Ministry of Education, Xi’an, Shaanxi, 710064, China
2CRRC Zhuzhou Electric Co., Ltd, Hengyang, Hunan, 412000, China
*2018125002@chd.edu.cn
*Corresponding author’s e-mail: 282775165@qq.com

Abstract: For cement mixture, water is indispensable and directly affects the performance of cement mixture of raw materials. Based on the research conclusion of alternating electromagnetic field, square wave excitation signal and 50-turn excitation coil were used to activate water through alternating electromagnetic field with different magnetic induction intensity (52.6mT, 97.8mT, 151.2mT, 193.6mT) at different flow rates (0.69m/s, 0.85m/s, 1.05m/s) to explore the effect of activated water on the performance of cement mortar. Through tests, the workability and compressive strength of cement mortar are improved, the water retention is better, and the apparent density is increased. The maximum increase of consistency is 34%, the layering degree is within 20mm, and the compressive strength of 7th day, 14th day and 28th day can be increased by 27.5%, 23.8% and 20.3%.

1. Introduction

Based on the research status of activated water mixing cement concrete at home and abroad, and considering the shortcomings of admixtures in cement concrete, the use of activated water mixing cement concrete can only improve the performance of the mixture by changing the physical and chemical properties of water (improving the activity of water). Although there are many studies on water activation, most of them are laboratory studies and have not been widely used in the construction industry. It can be seen that there is still a great development space for the application of activated water. B. Siva Konda Reddy [1] and R. Malathy [2] carried out the experiments of mixing and curing concrete with magnetized water. The results show that the compressive strength of concrete with magnetized water has been improved to varying degrees. Iman Abavisan [3] directly treated hardened concrete cube test blocks with alternating magnetic field, and its compressive strength increased by 7.78%. Han Zhongfan [4] applied electric field to treat water mixing cement, and the compressive strength of cement stone could be increased by 20%. Huang Liubin [5] directly treated cement pulp with high-frequency electric field, and its fluidity and hardening strength were improved. Ning Peng [6] and Liu Zhiwen [7] of Chang ‘an University used high voltage electrostatic field and high frequency electric field activated water to mix cement concrete with different strength grades, and found that the workability, strength and microstructure of concrete were improved. The former Soviet Union was the first to apply activated water mixture to engineering construction, activated water concrete is used at Salatov construction sites and seawalls built by Black Sea Construction Corporation. There are also a few projects in China, such as the 893 Project frame beam column,
Sichuan Demian expressway and passenger station, Zhejiang Yuyao Linshan pump station and so on using activated water concrete. The activated water mixing concrete produced by German magnetized water equipment is used in Beijing airport and subway station, national theater and stadium, and its performance has been greatly improved and good economic benefits have been obtained [8]. So, the activated water can improve the performance of the mixture to a certain extent, and has certain application value.

At present, the research on strengthening mechanism and mixing technology of activated water on concrete is not in-depth. Moreover, there is no detailed theoretical research and mature application technology on the improvement of cement mixture performance by activated water. Therefore, this article uses alternating electromagnetic field activated water for the mixing of cement mortar, and explores the effect of activated water on the improvement and improvement of cement mortar performance.

2. Electromagnetic Activated Water System

The alternating electromagnetic field activated water system is consists of an alternating electromagnetic field test platform, variable frequency water pump, water tank, flowmeter and pipeline (see figure 1). The water is treated by continuous circulation. The whole system can be controlled by adjusting water-saving pump gear and parameters of alternating electromagnetic field test platform. The alternating electromagnetic field test platform shown in figure 1 is built, which is composed of signal generator, signal transmission line, power amplifier, output cable, excitation coil and oscilloscope. The excitation coil is wound on a PVC plastic pipe, and the material is enameled copper wire. Coil parameters shall be determined according to the pipeline, with an inner diameter of 32mm, an outer diameter of 36mm and a wire diameter of 2mm.

![Diagram of Alternating Electromagnetic Field Activated Water System](image_url)

**Figure 1. Alternating Electromagnetic Field Activated Water System**

2.1 Activation Index of Water

At present there is no direct detection of water molecule clusters size instrument, and no direct defines the index of water activity. Generally, changes in water activity are reflected by testing the physical and chemical properties of water such as density, viscosity, osmotic pressure, surface tension, PH value, conductivity, $^{17}$O NMR, infrared spectroscopy, Raman spectroscopy and absorbance. The operation of density, viscosity, osmotic pressure and other indicators is complicated and the test has a larger error. The surface tension, PH value and conductivity indexes are obtained through the conversion of electronic components with high precision. The $^{17}$O NMR spectrum is the most direct reflection of the structural changes of water molecular clusters. The average relative size of water molecular clusters is represented by measuring the half-amplitude width of the vibration frequency of water. However, the detection price is expensive and the test cost is too high. Considering operability and economy, surface tension, PH value and electrical conductivity of water are selected for testing.
2.2 Magnetization Process
In the research of water magnetization mechanism, hydrogen bond mutation theory is widely accepted. The theory holds that the hydrogen bonds between water molecules are twisted or broken under magnetic field energy, which increases the number of small molecules and single molecules of water, and thus increases the activity of water. The alternating magnetic field radiates energy to water body along with the current thermal effect, which makes the cohesion of water molecules decrease, the surface tension drops and the solubility increases.

The variable electromagnetic field activated water system has many adjustable parameters, such as coil turns, excitation signal waveform and frequency, etc. Any combination of waveform, frequency and turns will produce different magnetic induction intensity. In this test, the number of turns of the coil is 50 turns and 100 turns, and the parameter combination with the greatest magnetic induction intensity is selected from many parameter combinations to test the physical and chemical properties of water. After 200min of water treatment, the physical and chemical properties of water were measured, as shown in table 1.

Table 1. Changes in Physical and Chemical Properties of Water

| Change Rate   | 50       | 100       |
|---------------|----------|-----------|
| Sine Wave     | 11.8%    | 12.8%     |
| Triangle Wave | 10.7%    | 12.0%     |
| Square Wave   | 12.3%    | 12.0%     |
| Trapezoidal Wave | 11.1% | 12.2%     |
| Activation Index |         |           |
| Surface Tension (Down) | 3.4% | 3.8%       |
| PH (Rise)     | 1.8%     | 2.2%      |
| Electrical Conductivity (Rise) | 3.4% | 3.8%       |
| Surface Tension (Down) | 12.8% | 12.2%     |
| PH (Rise)     | 3.4%     | 3.8%      |
| Electrical Conductivity (Rise) | 0.7% | 0.9%       |
| Velocity of Water (m/s) | 0.69 | 0.69      |
| Magnetic Induction (mT) | 193.6 | 97.8     |
| Velocity of Water (m/s) | 0.85 | 0.85      |
| Magnetic Induction (mT) | 193.6 | 97.8     |
| Velocity of Water (m/s) | 1.05 | 1.05      |
| Magnetic Induction (mT) | 193.6 | 97.8     |
| Velocity of Water (m/s) | 0.69 | 0.69      |
| Magnetic Induction (mT) | 193.6 | 97.8     |
| Velocity of Water (m/s) | 0.85 | 0.85      |
| Magnetic Induction (mT) | 193.6 | 97.8     |
| Velocity of Water (m/s) | 1.05 | 1.05      |

After comprehensive comparison of the surface tension, PH value and conductivity of the treated water, the final selection of 50 turns coil, square wave as the excitation signal water activation treatment effect is better. After holding the treated activated water still, its surface tension can be maintained for about 25 min and its PH value can be maintained for at least 30 min.

3. Test Conditions and Working Conditions

3.1 Raw Materials

3.1.1 Mixing Water
The mixing water used in the test was the tap water in Xi’an and the tap water treated with an alternating electromagnetic field. The water used met the relevant requirements of the Standard for Water for Concrete (JGJ 63-2006) [9]. The water activation treatment parameters are shown in table 2 (where the first group is untreated tap water).

Table 2. Water Activation Treatment Parameters

| Test Group | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|------------|---|---|---|---|---|---|---|---|---|----|----|----|----|
| Magnetic Induction (mT) | 193.6 | 193.6 | 193.6 | 151.2 | 151.2 | 151.2 | 97.8 | 97.8 | 97.8 | 52.6 | 52.6 | 52.6 |
| Velocity of Water (m/s) | 0.69 | 0.85 | 1.05 | 0.69 | 0.85 | 1.05 | 0.69 | 0.85 | 1.05 | 0.69 | 0.85 | 1.05 |

3.1.2 Cement and Sand
P.O42.5 ordinary portland cement was used in the test. Cement performance was tested according to the General Portland Cement (GB 175-2007) [10] standard, which meets the standard and can meet the requirements for use. Using medium sand to mix cement mortar can not only satisfy workability but
also save cement consumption. Its quality conforms to the relevant provisions of Standards for Quality and Inspection Methods of Sand and Stone for General Concrete (JGJ 52-2006) \cite{11} and Sand for Construction (GB/T 14684-2011) \cite{12}, and all the sand has passed through a square sieve with a 4.75 mm aperture. Before the test, the sand was dried to reduce the influence of moisture in the sand.

3.2 Determination of Cement Mortar Mix Ratio
In this paper, the mixing ratio design of M20 cement mortar is designed in accordance with the Design Rules for Mixing Ratio of Masonry Mortar (JGJ/T 98-2010) \cite{13}. According to the test procedure and economic rationality analysis, the cement mortar with Water-Cement ratio of 0.77 is selected as the mixing ratio: cement: sand: water = 1:3.38:0.77. The actual amounts of cement, sand and water in the test were 3 kg, 10.14 kg, and 2.31 kg.

3.3 Determination of Test Content
Determine the magnetic induction intensity of the alternating electromagnetic field activated water system, the length of the water cycle treatment time and the water flow rate, and study the changes in the performance of the alternating electromagnetic field activated water mixing cement mortar. Testing of cement mortar is carried out in accordance with the relevant requirements of Standard Test Methods for Basic Performance of Building Mortar (JGJ/T 70-2009) \cite{14}. Tests the consistency, stratification and apparent density of fresh mortar as well as the compressive strength of hardened mortar.

4. Test Results and Analysis
Cement mortar is made by water mixing after alternating magnetic field treatment for 60 minutes. The test results of freshly mixed mortar are shown in table 3.

| Test Group | Consistency (mm) | Change Rate (%) | Stratification (mm) | Change Rate (%) | Apparent Density (kg/m³) | Change Rate (%) |
|------------|-----------------|----------------|---------------------|----------------|--------------------------|----------------|
| 1          | 53              | -              | 10                  | -              | 2225.1                   | -              |
| 2          | 68              | 28.3           | 12                  | 20             | 2251.9                   | 1.2            |
| 3          | 71              | 34.0           | 16                  | 60             | 2247.7                   | 1.0            |
| 4          | 66              | 24.5           | 15                  | 50             | 2246.1                   | 0.9            |
| 5          | 58              | 9.4            | 4                   | -60            | 2263.4                   | 1.7            |
| 6          | 61              | 15.1           | 7                   | -30            | 2269.0                   | 2.0            |
| 7          | 54              | 1.9            | 6                   | -40            | 2260.1                   | 1.6            |
| 8          | 70              | 32.1           | 4                   | -60            | 2260.0                   | 1.6            |
| 9          | 64              | 20.8           | 6                   | -40            | 2262.6                   | 1.7            |
| 10         | 59              | 11.3           | 5                   | -50            | 2260.4                   | 1.6            |
| 11         | 62              | 17.0           | 7                   | -30            | 2254.0                   | 1.3            |
| 12         | 56              | 5.7            | 10                  | 0              | 2251.1                   | 1.2            |
| 13         | 55              | 3.8            | 9                   | -10            | 2250.9                   | 1.2            |

4.1 Consistency of Cement Mortar
From table 3, the consistency of cement mortar mixed with activated magnetic field activation water is greater than that of ordinary mortar, and its consistency can be increased by about 1.9-34%, and the fluidity of the mortar is significantly improved. As shown in figure 2, the relationship between cement mortar consistency and magnetic induction intensity is a multi-extreme curve. When the magnetic induction strength is less than 200mT, a low magnetic field should be used at low flow velocity to obtain better workability for mortar mixed with activated water. When the magnetic induction strength is large, the flow rate can be appropriately increased to increase the water treatment capacity. Excessive consistency caused by high water-cement ratio will bring about the mortar to appear bleeding and segregation phenomenon, which will affect the compactness and strength. But the mortar mixed with alternating magnetic field activated water improves its consistency without sacrificing other properties, which may obtain better workability for pumping mortar and shotcrete mortar.
4.2 Stratification of Cement Mortar

From table 3, the water retention of cement mortar mixed with activated water has been improved, and the stratification can be reduced by about 60% compared with ordinary mortar. As shown in figure 3, at 193.6mT the degree of stratification of the mortar is greater than that of the ordinary mortar, and when the flow rate is 0.85m/s, the stratification degree is greatly improved. The stratification degree of cement mortar is within 20mm, and the mortar with the stratification degree less than 10mm has no shrinkage cracks after hardening, so the water retention of the mortar is better. Cement mortar mixed with activated water is not easy to drain and segregate during transportation and storage, and can improve volume stability of mortar without cracks.

4.3 Apparent Density of Cement Mortar

From table 3, the apparent density of the mortar mixed with the activated water has been increased, but the increase is not significant, which can increase by about 0.9-2%. As shown in figure 4, activating water mixing and cement mortar helps to improve the apparent density of mortar. The peak values of apparent density of each curve reach at 150mT of magnetic induction strength and reach the maximum at 0.85m/s of flow rate. For larger apparent density, velocity of 0.69m/s can be used for small or large magnetic field, while 0.85m/s should be used for medium magnetic field. The increased apparent density of mortar mixed with activated water means that the voids and air bubbles in the mortar are reduced and the volume occupied by the mortar is filled with water, sand and hydration products, which can improve the problem of air bubbles in the mortar. Therefore, the mortar prepared with alternating electromagnetic field activated water has the advantages of small voids, uniform distribution and good compactness compared with ordinary mortar.
enter the interior of micro-cracks on the surface of cement particles to promote the hydration reaction of cement, generate more colloids and improve the cohesiveness and fluidity of cement mortar.

Bleeding caused by sand sinking will directly affect the workability of the mortar. However, activated water accelerates cement hydration, which increases the viscosity of the cement slurry, so reduces the sand sinking speed. At the same time, some of the bleeding channels are blocked and the surface tension of water is small, which can reduce the capillary suction, so the bleeding is reduced. Decreasing water surface tension can also weaken the restraining effect on fine sand particles. Water enters the gap between the sand grains to form a concave-shaped water surface with a thin inner and outer thickness. The surface tension of the water interacts with the sand grains to form an adhesive force that hinders its movement. Surface tension and surface free energy of activation water are small, so that the force between fine sand particles is reduced. Fine sand particles can move freely and the distribution of cement hydration products is uniform, so the mortar workability can be improved.

4.4 Compressive Strength of Cement Mortar

The changes of the strength of cement mortar with age under different test conditions are shown in table 4.

| Test Group | 7th day (MPa) | Percent Increase (%) | 14th day (MPa) | Percent Increase (%) | 28th day (MPa) | Percent Increase (%) |
|------------|---------------|---------------------|---------------|---------------------|---------------|---------------------|
| 1          | 15.3          | —                   | 21            | —                   | 24.1          | —                   |
| 2          | 16.4          | 7.2                 | 23.0          | 9.5                 | 26.9          | 11.6                |
| 3          | 17.6          | 15.0                | 24.7          | 17.6                | 28.4          | 17.8                |
| 4          | 17.4          | 13.7                | 23.5          | 11.9                | 28.0          | 16.2                |
| 5          | 19.1          | 24.8                | 25.5          | 21.4                | 28.7          | 19.1                |
| 6          | 19.5          | 27.5                | 26.0          | 23.8                | 29.0          | 20.3                |
| 7          | 18.9          | 23.5                | 25.0          | 19.0                | 28.3          | 17.4                |
| 8          | 18.5          | 20.9                | 24.4          | 16.2                | 27.4          | 13.7                |
| 9          | 18.7          | 22.2                | 24.6          | 17.1                | 27.7          | 14.9                |
| 10         | 18.3          | 19.6                | 24.3          | 15.7                | 26.9          | 11.6                |
| 11         | 17.4          | 13.7                | 23.0          | 9.5                 | 26.0          | 7.9                 |
| 12         | 17.7          | 15.7                | 23.8          | 13.3                | 26.4          | 9.5                 |
| 13         | 17.2          | 12.4                | 22.7          | 6.3                 | 25.9          | 7.5                 |

From table 4, the compressive strength of cement mortar at 7th day mixed with activated water is higher than that of common mortar, which can be increased by about 7.2-27.5%. As shown in figure 5, the compressive strength at 7th day curve of each flow rate reaches its peak value near 150mT over the whole magnetic field range. At the flow rate of 0.85m/s, the compressive strength improvement effect is the best. The compressive strength at 14th day of mortar can be increased by about 6.3-23.8%, at 28th day of mortar can be increased by about 7.5-20.3%. From figure 6-7, the influence rule of magnetic induction intensity on the compressive strength curves of 14th day and 28th day is similar to that of 7th day; only when the magnetic induction intensity is high, the water velocity has a great influence on the compressive strength.
Based on the above analysis, the compressive strength values of cement mortar specimens mixed with activated water at all ages are higher than those of common mortar. Among them, the magnetic induction intensity is 151.2 mT and the water flow velocity is 0.85 m/s, the maximum compressive strength is obtained. There is a significant increase by 27.5% at 7th day, 23.8% at 14th day, and 20.3% at 28th day. Most of the cement mortar test pieces pressed by the press only showed very small cracks, and there was no crushing. This indicates that activated water causes uniform distribution of hydration products and sand grains in cement mortar. High cohesion between materials and compact filling results in higher strength and less crushing of cement mortar.

Mortar is a solid-liquid-gas three-phase dispersion system consisting of sand particles, cement slurry and air. Sand particles and air bubbles are distributed in the cement slurry. The uniformity of the particles of each material, the compactness of the filling, and the degree of hydration of the cement will affect the strength of the mortar. The increase in mortar strength can be explained by the fact that activated water promotes cement hydration and increases gel formation. Water first undergoes a hydration reaction on the surface of the cement particles to form a colloidal film, and this film hinders further cement hydration, thereby limiting the strength of the cement. The alternating electromagnetic field activates many single-molecules and small-molecular water masses in activated water, and their low surface tension and high activity make it easier to enter the interior of cement particles and generate more crystals and colloidal particles. Hydration continues to form a gel which has high strength and deformability. Compared with tap water mixing mortar, the pores in cement slurry activated by alternating electromagnetic field are filled with hydrated gel. Therefore, the more hydration products, the higher the workability of the cement slurry, and the more dense the structure after combining with the sand particles, so the overall strength of the mortar is improved.

### 4.5 Deviation Coefficient of Compressive Strength

The deviation coefficients under different test conditions are shown in table 5.

| Test Group | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|------------|---|---|---|---|---|---|---|---|---|----|----|----|----|
| 7th day (%)| 5 | 4.4 | 4.1 | 4.6 | 4.2 | 3.8 | 4.8 | 4.3 | 4   | 4.3 | 2.2 | 1.5 | 3.3 |
| 14th day (%)| 4.9 | 4.4 | 4.1 | 4.5 | 4.3 | 4.6 | 4.7 | 5   | 4.4 | 4.5 | 3.9 | 3.6 | 3.5 |
| 28th day (%)| 4.4 | 3.8 | 3.7 | 4.3 | 3.7 | 3.8 | 3.9 | 4.5 | 3.8 | 4.6 | 2.8 | 2.6 | 3  |

The smaller the dispersion coefficient is, the more stable the mortar quality is, and the smaller the variation of its compressive strength is. From Table 5, the deviation coefficient of the strength of the mortar mixed with the activation water is smaller than the deviation coefficient of ordinary mortar. When the alternating magnetic field is weak, the deviation coefficient will be significantly reduced. The minimum values of strength deviation coefficients for 7th day, 14th day and 28th day mortar are all around 50 mT, and the decrease is obvious at 7th day.
5. Conclusion

Based on the results reported in the research work, some conclusions can be drawn:

1. Alternating electromagnetic field activation water can increase the fluidity of cement mortar with a water-cement ratio of 0.38 by 3% -12%.
2. Alternating electromagnetic field activation water can increase the consistency of cement mortar by about 1.9-34%, and the fluidity of mortar is significantly improved.
3. Alternating electromagnetic field activation water can reduce the stratification of cement mortar by about 60% compared with ordinary mortar, and the water retention is improved.
4. Alternating electromagnetic field activation water makes the apparent density of cement mortar increase but not large, it can be increased by about 0.9-2%.
5. Alternating electromagnetic field activation water makes the compressive strength of cement mortar of different ages increase obviously, and can reduce the deviation coefficient of cement mortar strength, which is beneficial to improve the stability of mortar strength.

The combination of alternating electromagnetic field activated water technology, vibration mixing technology and new mixing construction technology can optimize the performance of cement mixture, which can provide reference for further research.

Acknowledgments

We would like to thank the Key Laboratory for Highway Construction Technology and Equipment of Ministry of Education. This work is supported by the National Natural Science Foundation of China (No. 51508031).

References

[1] Siva, K.R., Vaishali, G.G., Sudarsana, R. (2014) Use of Magnetic Water for Mixing and Curing of Concrete. J. International Journal of Advanced Engineering Research and Studies, IV (1):93-95.
[2] Malathy, R., Karuppasamy, N., Baranidharan, S. (2017) Effect of Magnetic Water on Mixing and Curing of M25 Grade Concrete. J. International Journal of ChemTech Research, 10(11):131-139.
[3] Abavisani, I., Rezaifar, O., Kheyroddin, A. (2016) Alternating Magnetic Field Effect on Fine-aggregate Concrete Compressive Strength. J. Construction and Building Materials, 134:83-90.
[4] Han, Z.F., Wang, S.C., Yao, F.Y. (1986) Experimental study on early intensity age of cement stone mixing electric field treatment water. J. Physics, 15 (09): 535-536, 556.
[5] Huang, L.B., Guan, J.T., Ding, G. (1997) Experimental study on improving physical properties of cement slurry by high-frequency electric field treatment. J. Physics, 26(11):674-678.
[6] Ning, P. (2013) Experimental study on the mechanism of electric field activated water mixing cement concrete. D. Chang'an University, Xi'an.
[7] Liu, Z.W. (2015) Study on performance of concrete mixed with electric field activated water. D. Chang'an University, Xi'an.
[8] Liu, J.J. (2005) Research and Application of Magnetized Water Concrete Technology. J. Construction Machinery Technology and Management, 8: 35-37.
[9] JGJ 63-2006. (2006) Standard for concrete water use. S. China Standard Press, Beijing.
[10] GB 175-2007. (2007) General portland cement. S. China Standard Press, Beijing.
[11] JGJ 52-2006. (2006) Standards for quality and inspection methods of sand and stone for general concrete. S. China Standard Press, Beijing.
[12] GB/T 14684-2011. (2011) Construction sand. S. China Standard Press, Beijing.
[13] JGJ/T 98-2010. (2010) Design code for mix ratio of masonry mortar. S. China Standard Press, Beijing.
[14] JGJ/T 70-2009. (2009) Standard test method for basic performance of building mortar. S. China Standard Press, Beijing.