Effect of Magnetized Water on Working Performance of Cement Mortar

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Abstract: Compared with common drinking water, magnetized water seems to have the potential to save water for concrete production. The main purpose of this paper is to combine theoretical analysis and experimental verification of multiple sets of comparative tests to study the effect of magnetized water on the performance of cement mortar. This paper starts with the structure of water and the mechanism of hydrogen bond formation, clarifies the activation mechanism of magnetized water, and combines the properties of magnetic field to activate water to explain the mechanism of magnetized water enhances the performance of cement mortar. Through a cross-contrast test that combines four magnetic field strengths and three mortar strength grades, it is found that when cement mortar is mixed with magnetized water, the compressive strength increases by about 20% compared with ordinary water mixing, and the maximum increase can be as high as 25.3%. Also, the additional strength obtained through the use of magnetized water meets the need to reduce the amount of cement in mortar, and at least 10% of cement can be saved when the design strength of the reference mix proportion is met.

1. Introduction

Increasing the strength of cement mixes, saving cement, and reducing project costs have always been a concern of the engineering community. The production and use of additives have caused many problems, such as the increased cost of ingredients and pollution to the environment. These problems are contrary to the themes of green environmental protection and energy conservation, as advocated by modern society [1-3]. Therefore, forward-thinking technicians began to focus on mixing water. To save and effectively use cement, some green environmental protection measures have been taken, one of which is to use magnetized water to mix cement mixtures. Water plays an important role in the production of cement concrete because it controls the hydration, workability, microstructure, strength, and durability of concrete [4]. Using magnetized water to mix cement has opened up a new way to save cement and to improve strength.

On the basis of research conducted at home and abroad regarding the mixing of cement concrete with magnetized water and considering the shortcomings of using admixtures when mixing cement concrete in engineering applications, the use of magnetized water to mix cement concrete improves the performance of the mixture by changing the physical and chemical properties of mixing water.
This method does not require chemical additives, will not cause pollution to the environment, has the advantages of green environmental protection, and is consistent with the themes of sustainable development. At present, the application of the magnetized water technology is still in the stage of experimental research and early stages of advances and applications at home and abroad. In actual projects, there have also been many successful examples. For example, FML Concretex GmbH, a German equipment expert, brought water treatment technology to North America. They built a cement concrete mixing plant that uses magnetized water as the mixing water, and the final hydration value and compressive strength increased by 10% to 40%; In China, Yadong Company of Beijing Urban Construction supplies magnetized water concrete for key projects, such as Capital Airport, National Theater, Beijing Subway, and National Stadium. Research and development of activated water technology is greatly significant in the modern concrete engineering and construction industry.

This article aims to conduct a theoretical analysis of the influence of magnetic field activation on the physical and chemical properties of water and the promotion of magnetized water on the hydration reaction of cement. The purpose is to explore the effect that magnetized water has on the comprehensive properties of cement mortar by combining theoretical analysis with an experiment of mixing cement mortar with magnetized water.

2. Mechanism Analysis

2.1. Mechanism Analysis of Magnetic Field Activating Water

Water is a polar molecule. When a strong magnetic field is applied, the water will show magnetization in the direction opposite to the magnetic field; water has pairs of electrons that cancel each other's magnetic moments. As a result, the orientation of some water molecules is induced. Because the possibility of matching orientations in water molecule clusters is reduced, they are restricted from forming water clusters, and the percentage of hydrogen bonding is decreased. In other words, an external magnetic field cuts and decomposes larger water clusters, making near-neutral water to be smaller water clusters, single water molecules, or double water molecules. These water molecules have strong activity, and there is a much higher number of active water molecules in magnetized water than in unmagnetized water. These free and active water molecules can change the various established chemical balances and make the system more complex changes.

When ordinary water passes through a magnetic field, previously connected "molecular clusters" are broken into individual water molecules. Because each water molecule acts like a small magnet, they align in one direction in an end-to-end fashion when they pass through a magnetic field (figure 1a). In addition, there are no separate water molecules; the molecules are connected to each other through hydrogen bonds, forming a group of small molecular clusters. When the clusters pass through a magnetic field, the number of molecules connected in a group is reduced to 5 or 6 molecules (figure 1b), and this causes its activity to become stronger.

2.2. Mechanism Analysis of the Effect of Magnetized Water on the Properties of Cement Mortar

When cement is wetted with water, hydration first occurs at the surface of the cement particles; thus, the cement particles are coated with a colloidal film. This layer of colloidal film hinders the further
hydration of cement particles, and this affects the cement strength. After the water is magnetized, the polar water molecules (O\textsuperscript{2-} and H\textsuperscript{+}) are rearranged from the polymer form into neat water molecules because of the Lorentz force. Thus, the electrical attractive force between water molecules is enhanced, and this makes it difficult to separate the molecules. If magnetized water, which has a stronger attraction between water molecules, is used to mix cement, it will cause water molecules to easily enter the interior of cement particles and help further hydration of cement. This makes the cement hydration more thorough and sufficient, and thus, it effectively improves the strength of cement and concrete.

Because of the influence that a magnetic field has on water, intermolecular hydrogen bonds are broken, and the external magnetic field cuts the original large water mass and decomposes it into smaller water clusters or single water molecules. The number of water molecules and small molecular groups is greatly increased, and the cohesion between water molecules becomes weak. This leads to an increase in the average space of water molecules, improved water activity, reduced surface tension, and increased permeability. With improved water activity, cement particles directly combine with single water molecules or small clusters of water molecules in the process of hydration. More water molecules easily penetrate through the film coating into the interior of each component phase of cement to participate in the hydration reaction of cement, which makes the hydration reaction more complete and causes it to penetrate deeper into the cement.

Moreover, when water is mixed with cement, the cement particles are surrounded by clusters of water molecules. The thickness of the water layer around cement particles is thinner than that of ordinary water under low magnetization and with a low density of water clusters. This situation reduces the water requirement for cement mixing, and the water-cement ratio decreases. This has a positive effect on properties, such as strength and durability of hardened cement paste. When mortar is mixed with magnetized water, regardless of whether there are small water molecular groups or single water molecules, strong polar water molecules or an activated water system, water more easily enters into the interior of cement from the surface. Thus, the hydration and hydrolysis of cement is deeper, and this makes it more fully and completely react.

3. Experiment Scheme

3.1 Effects of Magnetized Water on the Properties of Mortar with Different Strength Levels

In this round of tests (denoted as Test 1), cement mortar of three different strength grades was designed and denoted as M7.5, M10, and M20. Ordinary water was treated by passing it through a magnetized water device with a magnetic field strength of 1.2T for 200 min. Samples of magnetized water were taken every 40 min and mixed separately with cement mortar of three strength grades. The properties of cement mortar of the same grade that were mixed using ordinary water were compared. Effects of magnetized water on the consistence, delamination, bulk density, and compressive strength of cement mortar with different strength grades was studied. Effects of magnetized water on the properties of cement mortar (consistence, delamination, bulk density, compressive strength) were determined according to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009) [8]. The test items are shown in table 1.

| Test Items          | Ages of Mortar |
|---------------------|----------------|
|                      | 0 days | 7 days | 14 days | 28 days |
| Consistence         | √      |        |         |         |
| Delamination        | √      |        |         |         |
| Bulk Density        |         |         | √        |         |
| Compressive Strength|         |         | √        | √        |

Table 1. Test Items of Test 1
3.2. Effects of Magnetized Water on Mortar Performance under Different Magnetic Field Intensities

In this round of tests (denoted as Test 2), four kinds of magnetized water treatment devices that had different magnetic field intensities (0.6T, 0.8T, 1.0T, and 1.2T) were used. A magnetizing device with different values of magnetic field strength were used for 200 min to treat ordinary water. Samples of magnetized water were taken every 40 min, and each was mixed with the cement mortar of strength class M20. The properties of cement mortar with the same grade that were mixed using ordinary water were compared. The influences that magnetized water has on the consistency, delamination, bulk density, and compressive strength of cement mortar under different magnetic field intensities were studied. Effects of magnetized water on the properties of cement mortar (consistence, layering, bulk density, and compressive strength) were determined according to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009). The test items are shown in table 2.

| Test Items         | Ages of Mortar |
|--------------------|----------------|
|                    | 0 days | 7 days | 14 days | 28 days |
| Consistence        | √      |        |         |
| Delamination       |        | √      |         |         |
| Bulk Density       |        |        | √      |         |
| Compressive Strength|      |        |        | √      |

3.3. Effects of Magnetized Water on Cement Dosage

In this round of tests (denoted as Test 3), which were based on the previous two groups of tests and the mix proportion of M20 strength grade mortar as the benchmark, four new mix proportions were designed to reduce cement by 5%, 10%, and 15%. The compressive strength of mortar mixed with magnetized water under the new mix ratio was measured, and the minimum amount of cement under the new mix ratio was studied when the compressive strength still reached the design strength of the original benchmark mix ratio. The effects of magnetized water on the properties of cement mortar (consistence, layering, bulk density, and compressive strength) were determined according to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009). The test items are shown in table 3.

| Test Items         | Ages of Mortar |
|--------------------|----------------|
|                    | 0 days | 7 days | 14 days | 28 days |
| Consistence        |        |        |         |
| Delamination       |        |        | √      |         |
| Bulk Density       |        |        |         | √      |
| Compressive Strength|      |        |        |

3.4. Test Preparation

3.4.1. Raw Materials

The cement used in this test was P.O 42.5 ordinary portland cement produced by Jidong Heidelberg (Jingyang) Cement Co., Ltd. The fine aggregate that was used was ordinary coarse sand, derived from the Weihe River in Xi’an; it had an apparent density of 2650 kg/m³, a loose bulk density of 1470 kg/m³, and a fineness modulus of 3.34. Before the test, a sieve with a nominal particle size of 5 mm was used to sieve out large-grained stones, which were thoroughly dried. The water used for the cement mortar mixing test was ordinary drinking water in Xi’an, and the magnetized water was treated using a permanent magnet magnetic field activation device.

3.4.2. Mix Ratio

In this test, three groups of strength grade cement mortar (M7.5, M10, and M20) were selected for
comparative tests. The mix ratio was designed in accordance with the Design Code for Mix Ratio of Masonry Mortar (JGJ/T 98-2010) [9]. The mix ratio of each strength grade was determined via calculation, and the design is shown in table 4.

| Strength Grade | Mix Ratio                  |
|----------------|----------------------------|
| M7.5           | Water: Cement: Sand =1.15:1:5.61 |
| M10            | Water: Cement: Sand =1.02:1:5.00  |
| M20            | Water: Cement: Sand =0.70:1:3.45   |

3.4.3 Stirring System
According our previous research and the actual situation of the test, the feeding sequence use in this test was water-cement-sand, and each substance was fed using a manual dumping method. This method avoids the dust and bucket sticking of cement and also prevents the material splashing that is caused by the water incompatibility during the initial stage of feeding. At the same time, the cement slurry and sand can be quickly and evenly mixed. Combined with the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009), the mixing time selected for this test was pre-mixing for 10s and stirring for 2min. A 1-6 gear adjustable speed mixer was used in the test. The pre-mixing speed was gear 1 (200r/min), and the stirring speed was gear 6 (1100r/min). The process and parameters are shown in figure 2.

![Figure 2. Stirring Process and Parameters](image)

4. Test Results and Analysis

4.1 Test and Analysis of Consistence
According to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009) consistence meter measurement procedure, the required indicators in Test 1 and Test 2 were each tested. Samples were immediately mixed and measured.

4.1.1 Test 1 Results and Analysis
Figure 3 shows consistence test results for mortars with different strength for Test 1.
As seen in figure 3, when the magnetic field strength was 1.2T and magnetized water was used to mix mortar of each strength level (M7.5, M10, and M20), the consistence increased with the continuous increase in the magnetized water treatment time. Also, the maximum growth amplitude was with a treatment time of 200min. The maximum increase in the consistency of the mortar for the three strength grades was 8.3% (M7.5), 8.6% (M10), and 7.0% (M20). When magnetized water was used to mix the mortar, the hydration reaction area increased, the reaction was more sufficient, and the consistence increased.

4.1.2. Test 2 Results and Analysis

The consistence test results for different values of magnetic field strength for mortar mixed with magnetized water in Test 2 are shown in figure 4.

As seen in figure 4, M20 mortar was mixed with magnetized water that was obtained after treatment with different values of magnetic field strength. The consistence increased with the continuous increase in magnetized water treatment time compared to the results with ordinary water. However, under different values of magnetic field strength, the increase in consistence was not very
large.

4.2. Test and Analysis of Delamination
According to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009) delamination instrument measurement procedure, the required indicators in Test 1 and Test 2 were respectively tested. Samples were immediately mixed and measured.

4.2.1. Test 1 Results and Analysis
Figure 5 shows the delamination test results for mortars of different strength levels in Test 1.

![Delamination Test Results](image1)

As seen in figure 5, when the magnetic field strength was 1.2T, the treated magnetized water was used to mix mortars with strength levels M7.5, M10, and M20. With prolonged magnetized water treatment time, delamination is significantly less than that with ordinary water. When the treatment time was 120-160 min, the degree of delamination for the mortars with three strength grades decreased the most. The maximum reductions of delamination reached 63.2% (M7.5), 64.7% (M10), and 76.3% (M20). Using magnetized water to mix mortar can make the combination of cement particles and water molecules more complete, reduce the degree of delamination, and improve the water retention of the mortar.

4.2.2. Test 2 Results and Analysis
The delamination test results of different values of magnetic field strength using magnetized water-mixed mortar in Test 2 are shown in figure 6.

![Delamination Test Results](image2)
As seen in figure 6, when magnetized water that was treated with different values of magnetic field strength was mixed with M20 mortar and the magnetized water treatment time was increased, the degree of delamination was significantly lower than the results obtained with ordinary water. This indicates that there was improved water retention in the freshly mixed mortar. When the treatment time was 160-200min, the delamination degree of mortar decreased the most.

4.3. Test and Analysis of Bulk Density

According to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009) densitometer measurement procedure, the required indicators in Test 1 and Test 2 were respectively tested. Samples were immediately mixed and measured. In the test, the mass of the capacity cylinder of the densitometer was $m_1=424.5g$, and the volume was the standard 1L. The bulk density was calculated as follows:

$$\rho = \frac{m_2 - m_1}{V} \times 1000$$  \hspace{1cm} (1)

where: $\rho$ - Mass density of mortar mixture (kg/m³);
$m_1$ - Mass of capacity cylinder (kg);
$m_2$ - Mass of capacity cylinder and sample (kg);
$V$ - Volume of capacity cylinder (L), 1L.

4.3.1. Test 1 Results and Analysis

Figure 7 shows the density test results for mortars of different strength levels in Test 1.
As seen in figure 7, the magnetic field strength was 1.2T and treated magnetized water was used to mix mortar with strength levels of M7.5, M10, and M20. With an increase in the magnetized water treatment time, the density increased significantly compared to the results obtained with ordinary water. For the three mortars with different strength levels, the maximum increases in density were 63.2% (M7.5), 64.7% (M10), and 76.3% (M20). Using magnetized water to mix mortar can make the cement particles and water molecules combine more closely and fully, increase the density, and improve the compactness of the mortar.

4.3.2. Test 2 Results and Analysis
The density test results for using different magnetic field strengths for the magnetized water-mixed mortar in Test 2 are shown in figure 8.
As shown in figure 8, M20 mortar was mixed with magnetized water that was treated with different magnetic field strengths. The density increased with an increase in magnetized water treatment time compared to the results obtained using ordinary water. Thus, the compactness of the mortar was improved. When the magnetic field strength was large and the water treatment time was 120 min or less, the density of the mortar increased greatly. If the selected magnetic field was small, the required water treatment time was 200 min. At the same time, the maximum increases in the mortar density under different magnetic field strengths are similar; specifically, the maximum increases were 1.3% (0.6 T), 1.0% (0.8 T), 1.4% (1.0 T), and 1.4% (1.2 T).

4.4 Test and Analysis of Compressive Strength

The size of the mortar compressive strength test piece in the test was a standard size: 70.7mm×70.7mm×70.7mm. Three groups of test pieces were prepared for tests of 7 days, 14 days, and 28 days for each pot of mortar mixed, and three specimens were made for each aging group. The curing time of the 6 groups of specimens in the same aging group was the same, and only the treatment time of the magnetized water was different. The compressive strength of the mortar was tested according to the Standard Test Method for Basic Performance of Building Mortar (JGJ/T 70-2009), and the effect of magnetized water on the strength of mortar was investigated.

4.4.1 Test 1 Results and Analysis

The compressive strength test results of different strength levels of mortar in different aging groups in Test 1 are shown in figure 9.
As seen in figure 9, for M7.5 mortar, the effect of magnetized water on the strength at 7 days is not very obvious. The maximum percentages of strength increased 7.8% in 7 days, 14.1% in 14 days, and 14.3% in 28 days. For M10 mortar, the maximum percentages of strength increased in 25.3% in 7 days, 21.2% in 14 days, and 14.8% in 28 days, and for M20 mortar, the maximum percentages of strength increased 18.9% in 7 days, 19.8% in 14 days, and 19.8% in 28 days. The effect of magnetized water on the early strength of low-strength level mortar is not very obvious. With increases in the amount of cement used and in the strength level, the rate of increase for high-strength mortar with magnetized water gradually increased. That is, when the mortar strength level was higher, the increase in compressive strength was greater. When the magnetic field strength was 1.2T, the mortar with strength level M10 was selected, and the effect of improving the compressive strength was better.

4.4.2. Test 2 Results and Analysis

The compressive strength test results for different magnetic field strength magnetized water-mixed mortar of different aging groups in Test 2 are shown in figure 10.
As seen in figure 10, when the magnetic field strength was 0.6T, for mortar specimens that were prepared with magnetized water the compressive strength at 7 days, 14 days, and 28 days increased by 13.8%, 11.8% and 11.9%, respectively compared to the results obtained using ordinary water. For a magnetic field strength of 0.8T, the compressive strength increased by 19.5% (7 days), 24.1% (14 days), and 21.0% (28 days); for a magnetic field strength of 1.0T, the compressive strength increased by 12.6% (7 days), 18.2% (14 days), and 18.9% (28 days); for a magnetic field strength of 1.2T, the compressive strength increased by 18.9% (7 days), 19.8% (14 days), and 19.8% (28 days). Among the four magnetic field strengths, the best improvement effect on the compressive strength of M20 mortar was 0.8T followed by 1.2T.

4.5. Cement Dosage

In the first two tests, magnetized water improved the compressive strength of fresh mortar. Therefore, on this basis, this round of test quantitative studies assessed whether the compressive strength of magnetized water mixed mortar can meet the design strength of mortar mix proportion when the amount of cement is reduced using different magnetic field strength treatments. In this round of tests, magnetized water was obtained using treatments of four different magnetic field strengths: 0.6T, 0.8T, 1.0T, and 1.2T. The amount of cement was reduced by 5%, 10%, and 15% on the basis of the M20 mortar basic mix ratio. The compressive strength of mortar at 28 days is shown in figure 11.

![Figure 10. Compressive Strength of Mortar at Different Aging Groups Mixed with Magnetized Water with Different Magnetic Field Strengths](image-url)
As seen in figure 11, when cement was reduced by 5% and 10%, the compressive strength curves of the magnetized water-mixed mortar under the four different magnetic field strengths all reach the design strength level. However, when the cement was reduced by 15%, the compressive strength curve was below the design strength level. In summary, for the design strength of M20 mortar to still meet 24MPa, the amount of cement can be reduced by at least 10% via mixing the mortar with magnetized water.

5. Conclusions

On the basis of the results reported in the research, the following conclusions can be drawn:

1. The activity of magnetized water is improved, and this effectively improves the performance of cement mortar.
2. Compared to ordinary water, magnetized water increases the consistence, reduces the delamination, and increases the bulk density of freshly mixed mortar.
3. Compared to ordinary water, magnetized water increases the mortar compressive strength by about 10% ~ 25%.
4. Under the premise of meeting the design strength of the reference mix proportion, magnetized water saves at least 10% of cement.

Through the study of the magnetized water mixing mortar, it can be seen that the magnetized water can improve the performance of cement mortar to a certain extent. The above experimental research can provide a certain reference for engineering application of activated water in cement mixtures and has broad application prospects for construction engineering.

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References

[1] Ke Lei, Huang Shijie, Shuai Xiwen, et al. Discussion on the adaptability of concrete admixture and cement and its influence on concrete performance [J]. Concrete, 2004 (10): 60-62
[2] Sun Zhenping, Jiang Zhengwu, Wang Yuji, et al. Adaptability of concrete admixture and cement [J]. Journal of Building Materials, 2002, 5 (1): 26-31
[3] Liu Zhiwen. Study on the performance of cement concrete mixed with electric field activated water [D]. Xi'an: Chang'an University, 2015
[4] V.S.S.Kaushik, V.R.N.V.D.Pavan, A.Deerendra prasad. Influence of Magnetized water on strength parameters of concrete [J]. International Journal For Research & Development in Technology, 2015, V3(5): 26-29
[5] Gao Changming. Introduction to environment-friendly characteristics of cement and concrete [J].

Figure 11. Compressive Strength of 28d Mortar after Quantitative Reduction of Cement

(c) Reduce Cement by 15%
China Concrete and Cement Products, 2003 (2): 1-4
[6] Ober Robert. Batch Water Conditioning Extends Workability [J]. Concrete Products, 2010, V113(1): 30
[7] Liu Jianjiang. Research on magnetized water concrete technology and application [J]. Construction Machinery Technology and Management, 2005, 8: 35-37
[8] JGJ/T 70-2009. Standard test method for basic performance of building mortar [S]. Beijing: China Standard Press, 2009
[9] JGJ/T 98-2010. Design code for mix ratio of masonry mortar [S]. Beijing: China Standard Press, 2010