Repair effect of magnesium phosphate cement and carbon fiber cloth on concrete structure

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Abstract. Magnesium phosphate cement (MKPC) is a useful by product from the extraction of lithium from salt lake brine (MS) and potassium dihydrogen phosphate (KH2PO4). The effects of roasting temperature, ratio, water-cement ratio and fly ash on the performance of magnesium phosphate cement were studied. The application of potassium magnesium phosphate cement in concrete repair and reinforcement in combination with carbon fiber cloth as a concrete reinforcement were also studied. Experimental results show that when the calcination temperature is at 1100°C, the calcination time is 1 hour, & when the mass ratio of magnesium oxide to potassium dihydrogen phosphate is 2:1, water-cement ratio is 0.2, and fly ash is 30%, the carbon fiber cloth improves the concrete beam’s load carrying capacity, flexural strength, as well as delay the appearance of concrete cracks and extension.

1. Introduction
In the natural environment, buildings are influenced by both the natural environment and the human environment. Therefore, the safety, durability and applicability of the structure will reduce the service life of the structure. If it is dismantled and rebuilt, it will be economically wasteful. Therefore, these buildings need to be repaired and reinforced[1]. Magnesium phosphate cement is an inorganic cementitious material that is new type and can be used for rapid repair[2][3]. Lithium magnesium slag and potassium dihydrogen phosphate were used to prepare environmentally friendly, economical, early-strength, and fast-hard materials, and their application in engineering practice was explored. In the engineering application research of potassium magnesium phosphate cement, the magnesium potassium phosphate cement has strong bonding ability through the tests of bending and splitting, and it has fast-hardening and early-strong engineering properties[4]. It is a good choice for rapid repair works.

At the same time, carbon fiber cloth has the characteristics of high strength, small quality, and thin thickness. The combination of carbon fiber cloth and magnesium phosphate cement will help us to repair the damaged structure and increase the bearing capacity of the structure[4].

2. Plain concrete experiment[6]

2.1. Experimental procedure Some text.

2.1. Plain concrete specimen production.
The production of concrete standard blocks is a key step in evaluating the bonding properties of phosphate cement repair materials. Using the same mixing ratio, a cylindrical concrete specimen with a 100-mm cube on one side, a 180-mm diameter, and a 200-mm height was prepared on a standard size. These samples are used for bonding cracking and bonding carbon-fiber reinforced concrete.
reinforcement tests. According to the proportion of Table 2, the concrete is formed, the mold is removed after 1 day, and put into a standard curing room for curing to 28 days, and can be used for the bonding test.

**Table 2 Plain Concrete Mixture Ratio and Strength Table**

| Ratio of ingredients /g | 28dstrength/ MPa |
|-------------------------|------------------|
| Portland cement         | Stone            | Sand | water | splitting | Pressure resistance |
| 1                       | 3.08             | 1.65 | 0.4   | 1.73      | 33.47               |

2.1.2. Elementary Strength Data of Plain Concrete Block

(1) Plain concrete splitting strength test

Splitting is the use of hydraulic testing machine to size 100mm × 100mm × 100mm plain concrete specimens split; the process of hydraulic testing equipment will show the load pressure \( F \)

Splitting strength test procedure is as follows:

(2) Concrete splitting strength test results are calculated and determination method as follows

1) The splitting strength of concrete is calculated from

\[ f_t = \frac{2F}{\pi A} = 0.637 \frac{F}{A} \]  (Formula 1)

\( f_t \) is the splitting strength of the concrete specimen (MPa)

\( F \) is the failure load of the specimen (N)

\( A \) is the splitting area of the specimen (mm²)

Splitting tensile strength accurate to 0.01 MPa

2) Determine the splitting strength of the specimen according to the following rules:

a. The average value of the three concrete specimens as the final strength value of the set of specimens (accurate to 0.01 MPa)

b. The difference between the maximum and minimum values of the three test specimens must be within 15% of the median value. Otherwise, remove both the maximum and minimum values, and take the median value as the splitting strength value of the set of specimens.

c. In this experiment, a non-standard test piece of 100mm×100mm×100mm was used. Therefore, according to the standard regulations, the size conversion factor should be multiplied by 0.85. The average breaking load of the splitting test is 31.95KN.

Therefore, use (Formula 1) to calculate

\[ F_n = 0.637 \frac{F}{A} \times 0.85 = 0.637 \times 0.85 \times \frac{31950}{10000} = 1.73 \text{Mpa} \]

(3) Cylindrical plain concrete compressive strength test

The compressive strength is to use a φ 180mm x 200mm cylindrical non-standard test piece to continuously and uniformly load the test piece until the test piece cannot withstand pressure.

Here are the test steps

The following are the data processing methods and results of compressive strength test:

\[ f_{\text{cc}} = \frac{4F}{\pi d^2} = \frac{F}{A} \]  (Equation 2)

Concrete compressive strength is calculated according to

In the formula, \( f_{\text{cc}} \) refers to the concrete compressive strength (MPa) and accurate to 0.01Mpa

\( F \) refers to specimen failure load (N)
2d refers to the test piece diameter (mm)

\[ d = \frac{d_1 + d_2}{2} \]

The test uses non-standard test pieces, and the results should be multiplied by a size conversion factor of 0.95. The average value of the failure load of the compression test is 896.13KN.

Therefore, use (Equation 2)

\[ f_{\text{cc}} = 0.95 \times \frac{\frac{896130}{3.14 \times 90}}{29014.3} = 33.47 \text{MPa} \]

The compressive strength value of cylindrical plain concrete is 33.47MPa.

3. Preparation of potassium magnesium phosphate cement

3.1. Experimental raw materials

The raw materials used in this experiment were magnesium oxide (MgO), a by-product of Qinghai Zhongxin Guoan Science and Technology Li2CO3 process, and potassium dihydrogen phosphate (KH2PO4), produced by Hongyan Reagent Factory of Hedong District of Tianjin. From the XRD spectrum of MS extracted from Figure 3.1, the content of magnesium oxide is very small, and the mineral components include magnesium hydroxide (Mg(OH)2) and magnesium borate (Mg3B2O6). Therefore, during the experiment, it needs to be calcined.

![Fig 3.1. X-Ray Diffraction Diagrams for MS](image)

3.2. Experimental Instruments

The instrument used for the calcination of this experimental project was the resistance furnace model SSX3-12-16 manufactured by Shanghai Yifeng Electric Furnace Co., Ltd. The compressive and splitting tests of concrete were done using the JES-2000A pressure testing machine manufactured by Wuxi Xidong Building Materials Equipment Factory. The instrument used for the final load test was a 1000KN structural fatigue tester using Tianhongshan Tester Co., Ltd.

3.3. Experimental scheme

3.3.1. MS Calcining Temperature

Since the content of magnesium oxide in the lithium magnesium slag is small and the condensing speed of the magnesium phosphate cement is faster, it is necessary to calcine the MS. Taking into account the calcination temperature, the relationship between the activity and the solidification time of the magnesium phosphate cement, the calcination temperature is 1100°C, and the calcination time is 1 hour as the calcining conditions for extracting MS.

3.3.2. MKPC mass ratio, water-cement ratio and fly ash parameters

While ensuring the fluidity of MKPC, 30% of the fly ash in the MKPC can significantly increase the bond strength between MKPC and plain concrete. This is due to the activity and physical filling of fly
ash. Because the MKPC slurry is more viscous and difficult to flow, a large amount of bubbles cannot be discharged in the middle of the bonding process, resulting in poor adhesion between cement and concrete. Adding fly ash can greatly improve the flowability of MKPC slurry, and also improve its compactness, making the bonding effect better. In addition, the addition of fly ash can reduce the manufacturing cost of MPKC. However, if the fly ash content is too large, the excess fly ash is basically inert and cannot be fully utilized, resulting in a decrease in strength.

To sum up, the water-cement ratio of the MKPC with paste concrete used in this project is finally determined to be 0.2, the mass ratio of magnesium oxide to potassium dihydrogen phosphate is 2:1, and the parameter of fly ash is 30%.

3.3.3. Carbon fibre cloth reinforced plain concrete
The experiment used reinforcement material is a 200 g Grade 1 carbon fiber cloth. The parameters of material quality ratio, water-cement ratio and fly ash have been determined. However, for carbon fiber and concrete adhesive materials, since carbon fiber and concrete are completely different materials, the carbon fiber cloth must be soaked and moistened in water to ensure the bonding strength of the interface between different materials. Then adjust the water-cement ratio at the paste location to 0.3 to ensure better bonding between the two at the interface.

4. Repair and Reinforcement Experiments

4.1. Concrete split repair experiment
The split 100mm × 100mm × 100mm concrete blocks shall be bonded using MKPC paste with the strongest bond strength, ie, the ratio of water to dust 0.2, mass ratio of 2:1, and fly ash parameters of 30%, curing at room temperature, testing 3h, 1d, 7d split tensile strength. The experimental results are 11.67 KN, 18.51 KN, and 21.38 KN, respectively. Compared with the original splitting tensile capacity of 31.95 KN, the bearing capacity values are restored to 36.53%, 57.93%, and 66.92% of the original values, respectively. It shows that MKPC does have a strong adhesive ability and the bonding with concrete is very fast.

4.2. Carbon fiber reinforced bearing capacity experiment

4.2.1. Cylindrical plain concrete reinforcement
On the side of plain concrete specimens of φ180 mm x 200 mm round cylinders, MKPC bonded carbon fibers with a water-cement ratio of 0.3, a mass ratio of 2:1, and fly ash parameters of 30% . Its compressive strengths at 3h, 1d, and 7d were 48.53MPa, 55.61MPa, and 56.23MPa, which were higher than the original average compressive strength at 35.23MPa, an increase of 37.75%, 57.85%, and 59.61%, respectively. It shows that MKPC paste carbon fiber has better reinforcement effect on concrete.

4.2.2. Reinforced concrete flexural reinforcement

Fig 4.1 Experimental setup

(1) Flexural reinforcement failure process
First, remove the concrete beam from the curing chamber and clean the surface. Next, brush the MKPC slurry on the bottom of the concrete beam. Then paste the carbon fiber cloth. The impregnated MKPC was coated on the surface and left at room temperature. The maintenance cycle is 7d. The carbon fiber size is the same as the beam size. The length is 1500mm and the width is 100mm.

(2) Strain collection during reinforcement

1) Concrete strain gauges (model number BX120-40AA, resistance value 120±0.1%, Gate width × gate length 5mm ×40mm) are glued on the left and right sides of the cross-center position of the concrete beam and the upper and lower sides respectively.

2) For the carbon fiber-bonded beam, use the same method to attach the carbon fiber surface. The concrete strain values were collected using a CML-1H strain force tester.

![Fig 4.2 Destruction of flexural reinforcement beams](image)

The load bearing capacity of flexural concrete beams was measured with a 1000KN structural fatigue tester of Tianhongshan Testing Machine Co., Ltd. During the experiment, it can be seen from Figure 3.3 that the bottom of the flexural reinforcement beam is stripped from the carbon fiber cloth, and the concrete is cracked. In the course of reaching the ultimate load of the flexural-reinforced beam, due to abrupt changes in the flexural rigidity at the end of the carbon fiber cloth, stress concentration occurs and the carbon fiber cloth is peeled off and destroyed. The cause of the separation of the beam body and fiber cloth is likely to be caused by large deformation of the beam, too dense bottom cracks, too wide cracks, low strength of the concrete, and improper pasting methods. For the peeling phenomenon, it can be considered to avoid the premature stripping of the fiber cloth by adopting measures such as controlling the rigidity of the beam section, strengthening the additional anchorage measures, and ensuring the sticking method, so as to fully exert its tensile strengthening effect[7].

4.2.3. reinforced concrete shear reinforcement

(1) Destruction process of shear reinforcement

1) According to the related introduction in "Technical specification for strengthening concrete structures with carbon fiber reinforcea polymer laninate", it can be seen that in the construction measures of shear reinforcement, the closed form of paste should be used preferentially. During this experimental study, since all operations are performed manually, the closed form of paste is preferred.

2) Shear concrete strain. First, the carbon fiber was attached to the bottom of the beam, and the closed U-shaped carbon fiber cloth was attached to the side of the beam every 300 mm. The carbon fiber strain was measured by attaching a strain gauge.
During the loading process of the shear reinforcement beam, there was no peeling phenomenon between the carbon fiber cloth and the beam body. When the beam body reached the ultimate load carrying capacity, the carbon fiber cloth also broke along with it.

3) Crack width measurement. Observe the extension of cracks in the full span of the beam while loading. After the cracks appear in the area of the beam, each time the load is increased, the crack width is read by a 40X crack width measurement microscope.

4) Measurement of Concrete Deflection. With dial indicator: bf-1 digital dial indicator, range 0-50mm, precision 0.01mm-0.0001mm.

4.2.4. Analysis of Experimental Results

(1) Stress strain

The stress and strain values of carbon fiber reinforced beams are shown in the figure:

![Stress-strain curve of unstrengthened beams](image1)

![Flexural reinforcement stress-strain curve](image2)

![Shear reinforcement stress-strain curve](image3)
The above figures 4.4a,b,c are the bearing capacity-strain curves of unconsolidated beams, flexural reinforcement beams and shear reinforcement beams respectively. From the figure, it can be seen that as the load increases, the concrete strain increases. In Figure b, when the load is less than 30KN, the tensile and compressive strain of the flexural reinforcement beam changes linearly with the load. When the load is greater than 30KN, the tensile strain increases due to the peeling between the carbon fiber and the concrete girder, and finally tensile failure occurs. Figure C. Shear Strengthened Beams. The tensile and compressive strains increase linearly when the load is less than 42 KN. When the load is greater than 42 KN, the carbon fiber cloth breaks and the tensile strain increases. Compared with the stress-strain curve of unstrengthened beams in Fig. a, the strain change amplitude after reinforcement is significantly reduced, which indicates that the reinforcement of carbon fiber cloth makes the bearing capacity of the concrete beams increase.

We can see that the photos of the damaged beams and the stress-strain data can be seen that the beam in the stress process is the first to reach the yield strength of the steel in the tension zone, its stress remains basically unchanged and the strain gradually increases. Then vertical horizontal cracks appear in the compression zone, indicating that the concrete in the compression zone has reached the ultimate compressive strain, and is finally destroyed due to concrete crushing. This is a typical method of damage to the beam[8].

(2) Crack width and deflection

In Figure 4.5 a and b are the bearing capacity-fissure width, deflection-capacity capacity curves of the MKPC strengthened beam, and the curve A is the shear reinforcement curve. Curve B is the flexural reinforcement, curve C is the unreinforced (virgin) beam, and D is the damage repair and bending reinforcement. From the comparison of the C and D curves of the bearing capacity-crack width graph a, the initial crack load of the unreinforced beam is 18 KN, and the initial crack load of the repair reinforcement is 12 KN. By comparing the three curves of A, B and C, it can be concluded that the initial crack load of shear reinforcement is 27KN, which is 1.5 times of the original initial crack load. Therefore, the application of carbon fiber cloth with MKPC can delay the occurrence of cracks in the concrete beam and The speed of extension shows that carbon fiber can improve the tensile properties of concrete. From the bearing capacity-deflection curve b, it can be seen that the carbon fiber cloth can improve the tensile strength and deformability of the concrete beam. The original maximum deflection value is 5.54mm, and the deflection value of the shear reinforcement beam before failure reaches 7mm. At the same time, in order to protect the test equipment during the test, when the beam has not reached
the ultimate deflection value, the dial indicator is removed in advance. If the test is continued, the deflection value will be greater, and the ultimate bearing capacity will reach 51KN. Therefore, the reinforcing effect of carbon fiber cloth on concrete beams is not only reflected in the improvement of bearing capacity, but also makes the tensile strength of the beam enhanced and the toughness increased.

4.2.5. Calculation of the original bearing capacity of concrete beams
Because the original bearing capacity value of the concrete beam in the test is the initial cracking value of the concrete, it is not the ultimate bearing capacity value. Therefore, through the theoretical calculation, the original bearing capacity limit value is obtained.

The concrete used in this test is C30 concrete, a double-reinforced rectangular section beam, b×h=100mm×150mm, L=1400mm, Protective layer thickness is 30mm, the reinforcing bars are four HRB335 steel bars with 4 φ of 8mm. According to the theoretical calculation results, the theoretical ultimate bearing capacity of the experimental C30 concrete is 38.56KN. Through the shear reinforcement, the ultimate bearing capacity reaches 51KN. Its ultimate bearing capacity is increased by 32%.

5. Conclusion
1) The product after calcining MS with the potassium dihydrogen phosphate makes magnesium phosphate cement (external reference 30% fly ash) has a good repairing effect on the damaged structure.
2) Carbon fiber cloth has a delay effect on the production and expansion of cracks in concrete structures, and has a reinforcing effect on tensile properties. It is a very good engineering reinforcement material. Through comparison of tests, it can be seen that carbon fiber cloth can improve the bearing capacity of concrete beams. From the stress strain and stress crack width chart, it can be seen that carbon fiber cloth can improve the toughness of concrete beams, delay the expansion of cracks, and effectively improve the yield strength.

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