Effect of using magnesium phosphate cement on the strengthening of concrete bonded with different fiber cloths

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Abstract. Magnesium phosphate cement prepared by lithium magnesium slag (MKPC) is a re-use of lithium extraction waste, and it is non-toxic. It is a new type of inorganic cementing material with high bonding strength with old concrete, with early strength and fast hard characteristics, which can meet the requirements of rapid repair. In this research, the effect of using magnesium phosphate cement on the strengthening of concrete bonded with different fiber cloths was studied. The experimental results showed that the effect of using magnesium phosphate cement on the strengthening of concrete bonded with carbon fiber cloth was obvious. But, the effect of reinforcing the glass fiber cloth on the plain concrete is not obvious.

1. Introduction
Concrete materials are widely used in the project, but due to the long-term physical, chemical and biological effects, concrete structures of many projects have been damaged to varying degrees, failing to reach the expected service life and causing economic losses. Therefore, in order to prolong the service life of concrete and reduce costs, research on repair materials and repair methods of concrete at home and abroad is always prevalent. For example, epoxy resin is a common adhesive repair material in the market, but epoxy resins often require the addition of functional fillers to achieve different functional applications, but some fillers are toxic heavy metals that endanger health and pollute the environment[1]. Therefore, a new type of quick repair material that is green and economical can meet market demands.

Magnesium phosphate cement prepared by lithium magnesium slag (MKPC) is a re-use of lithium extraction waste, and is non-toxic. It is a new type of inorganic cementing material with high bonding strength with old concrete, with early strength and fast hard characteristics, which can meet the requirements of rapid repair. Based on our previous research[2], this paper further studies the effect of using MKPC on the repair effect of concrete with different fiber cloths on the surface of plain concrete.

2. Experiment

2.1 Raw materials
The magnesium residue used in this study was byproduct of Li2CO3 obtained from Qing Hai Citic Guoan Technology Development Co., Ltd, Qing Hai, China. And the chemical compositions of the residue are in Table.1[2]. Fig.1 shows the XRD diffractogram of magnesium residue, showing that the According to previous study[3], the α-MgO used in this research was obtained from magnesium residue with calcination time of 1 hour at 1100 ℃. And the potassium dihydrogen phosphate (KH2PO4) in this research was purchased from Hedong District Hongyan Reagent Factory in Tianjin.
Table 1. The composition of magnesium hydroxide residue after producing Li$_2$CO$_3$

| Composition | Mg$^2+$ | B2O3 | Ca$^{2+}$ | Na$^+$ | Cl$^-$ | SO$_4^{2-}$ | Li$^+$ | LOI* | Total |
|-------------|---------|------|----------|--------|--------|-----------|-------|------|-------|
| Mass fraction /% | 59.22   | 4.91 | 0.33     | 0.027  | 0.36   | 0.92      | 0.45  | 0.25 | 32.55 | 99.02 |

Figure 1. XRD diffractogram of magnesium hydroxide residue after producing Li$_2$CO$_3$

2.2 Preparation of plain concrete
The production of plain concrete test pieces is a key step in evaluating the strengthening properties of magnesium phosphate cement repair material. The concrete is performed according to the mixtures design in Table 2, and then placed into standard moulds with dimensions of 40mm × 40mm × 160mm for 24h. Finally, put concrete test pieces in the standard curing room after demoulding.

Table 2. The mixtures design and strength of plain concrete

| Ratio of components | 28d/MPa |
|---------------------|---------|
| Portland cement     | 3.08    |
| Stone               | 1.65    |
| Sand                | 0.4     |
| Water               |         |
| Flexual strength    | 8.43    |
| Compressive strength| 33.47   |

2.3 Experimental method
According to previous study[2], the mass ratio of magnesium oxide to potassium dihydrogen phosphate was set to 2:1. However, the fiber cloth and concrete are completely different materials. The water-cement ratio (W/C) of MKPC should be found to stick fiber cloth and concrete together. Therefore, the water-cement ratio of MKPC were set to 0.2, 0.25, 0.3 and 0.4 respectively in this research. Firstly, mixed magnesium residue with potassium dihydrogen phosphate and stirred for 2 minutes. Then added a certain amount of water and stirred at low speed for 1 minute. After that, stirred paste at high speed for 30 seconds. Finally, the fiber cloth was attached to the side of a standard plain concrete specimen of 40 mm × 40 mm × 160 mm using the prepared MKPC cement slurry, and then placed under room temperature conditions. The strength of samples was tested at different ages[3].

3. Results and Analysis
3.1 Effect of using magnesium phosphate cement on the strengthening of plain concrete bonded with carbon fiber cloth
Figure 2 shows the experimental process of carbon fiber cloth pasted plain concrete. Figure 3 shows the strengthening effect of different water-cement ratios of MKPC on the flexural strength of concrete bonded with carbon fiber cloth. The experimental results show that when the water-ratio of MKPC was less than 0.3, the strengthening effect of carbon fiber on the flexural strength of plain concrete was
strengthened as the increase of water-cement ratio. For example, the flexural strength of plain concrete with carbon fiber cloth curing for 7d were 10.82MPa, 16.29MPa and 20MPa when the water-ratio of MKPC were 0.2, 0.25 and 0.3, respectively. Compared with the flexural strength of 8.43 MPa for the original plain concrete specimens, the flexural strength of the carbon fibre reinforced specimens increased by 28.4%, 93.2% and 137.2%, respectively. That is, when the water-cement ratio increases, the MKPC slurry wets the carbon fiber more thoroughly, and the carbon fiber cloth adheres better to the concrete. However, as shown in Figure 3, it could be seen that the flexural strength had a tendency to decrease as the value of water-ratio reached to 4. On one hand, higher water-ratio will reduce the cementitious property of MKPC paste. On the other hand, excessive water will result in shrinkage of MKPC in the later period. Therefore, the best water-ratio in this research was 0.3.

In addition, the experimental results show that the concrete which was pre-wetted in the process of pasting the carbon fiber could improve the flexural strength of the concrete. For example, the flexural strength of concrete without pre-wetting was 20MPa, but 22.82MPa after pre-wetting, increasing about 14.1%.

![Figure 2. The experimental process of carbon fiber cloth paste plain concrete](image)

![Figure 3. The flexural strength of concrete with carbon fiber cloth in different water-cement ratios of MKPC](image)

### 3.2 Effect of fly ash content of MKPC on the strengthening of plain concrete bonded with carbon fiber cloth

According to 3.1 analysis, the water-ratio of MKPC after mixing fly ash was set to 0.3. Table 3 shows the effect of fly ash content of MKPC on flexural strength of plain concrete bonded with carbon fiber cloth. It can be clearly seen that the addition of fly ash to magnesium phosphate cement significantly enhanced the flexural strength of plain concrete bonded with carbon fiber cloth. For example, when the fly ash content was 10%, its flexural strength was 24.388 MPa, but 22.816MPa for that without fly ash, increasing about 6.1%. Taking into account the cost, the best fly ash content in this research was 30%.

| Fly ash content | 3h/MPa | 7d/MPa | 1d/MPa |
|-----------------|--------|--------|--------|
|                 |        |        |        |

![Table 3. Effect of fly ash content of MKPC on flexual strength of plain concrete with carbon fiber cloth](image)
3.3 Effect of using magnesium phosphate cement on the strengthening of plain concrete bonded with glass fiber cloth

Figure 4 shows the experimental process of glass fiber cloth pasted plain concrete. According to 3.1 results, the water-ratio of MKPC used in bonding plain concrete with glass fiber cloth was set to 0.3. Here, the number of glass fiber cloth layers were set to 1, 2 and 3 aimed to pasted plain concrete because of lower strength of glass fiber cloth itself. Table 3 shows the effect of the number of glass fiber layers on the flexural strength of concrete. The experimental process showed that all the glass fiber cloths and the concrete block broke at the same time. Combined with the flexural strength data in Table 4, it can be inferred that due to the low strength of the glass fiber cloth itself, the effect of reinforcing the glass fiber cloth on the plain concrete is not obvious.

![Figure 4. The experimental process of glass fiber cloth paste plain concrete](image)

Table 4. The effect of the number of glass fiber layers on the flexural strength of concrete

| Glass fiber layers | 3h    | 7d    |
|-------------------|-------|-------|
| 1 layer/MPa       | 11.24 | 11.57 |
| 2 layers/MPa      | 10.08 | 11.33 |
| 3 layers/MPa      | 11.32 | 10.98 |

4. Conclusions

This test studies the effect of using magnesium phosphate cement on the strengthening of concrete bonded with different fiber cloths. According to the mentioned results, we can clearly draw the following conclusions:

1. The effect of using magnesium phosphate cement on the strengthening of concrete bonded with carbon fiber cloth was obvious. And the best water-ratio of MKPC on the flexural strength of concrete bonded with carbon fiber cloth was 0.3. In addition, the concrete which was pre-wetted in the process of pasting the carbon fiber could improve the flexural strength of the concrete.

2. The effect of fly ash content of MKPC on flexural strength of plain concrete bonded with carbon fiber cloth was well. And the best fly ash content in this research was 30%.

3. The effect of reinforcing the glass fiber cloth on the plain concrete is not obvious.

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