Study on Axial Compression Test of Corroded Reinforced Concrete Columns Reinforced by MPC Bonding CFRP

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Abstract. In this paper, reinforced concrete was first reinforced by magnesium phosphate cement (MPC) bonding carbon fiber sheets (CFRP). The axial compression test was conducted to evaluate the property of the MPC-CFRP reinforcement corroded reinforced concrete column. The results showed that the MPC-CFRP reinforcement corroded reinforced concrete columns had better structural bearing capacity and ductility in the process of compression failure.

1. Introduction
Structural adhesives have special advantages in construction and bonding effect. But there are also problems such as poor durability, poor fire resistance, environmental protection, and uneconomic issue. In this paper, the authors put forward the formation of MPC-CFRP by using magnesium phosphate cement (MPC) instead of structural adhesive to bond CFRP. MPC has the advantages of good conductivity, promising permeability, high bond strength, rapid solidification and hardening, superior corrosion resistance to steel and so on[1-3]. It was found that the effective binding coefficient of MPC bonding CFRP was higher than that of epoxy resin, and the strength model of MPC binding CFRP confined concrete column was in conformity with the existing theoretical model[4]. Based on the above research results, MPC bonding CFRP was innovatively used to reinforce the corroded reinforced concrete and the reinforcement effect was studied.

2. Test scheme

2.1. Raw materials
The used cement was P.O 42.5. The stone was 5~20mm continuous graded macadam. The sand was river sand with density of 2.7g/cm³ and fineness modulus of 2.56. Water reducing agent was Polycarboxylic Water Reducing Agent with reduction rate of 23%. The sodium chloride was industrial
purity with the NaCl content of more than 98%. The content of NaCl in concrete was controlled as 3% of cement by mass.

The density of MgO used in MPC was 3460kg/m³ with specific surface area of 806kg/m³ and the compositions and physical properties shown in Table 1. The potassium dihydrogen phosphate was industrial grade with purity of 98%. The purity of the retarder borax was 99.5%.

Carbon fiber sheets(CFRP) was offered by Japan torayn grade I with type of UT70-30. The thickness was 0.19mm and the surface density standard value was 300g/m². The standard value of tensile strength, tensile modulus and fracture strain were 4200g/m², 210GPa and 0.02.

| Table 1. The compositions and physical properties of MgO. |
|---------------------------------|
| sample                  | MgO   | CaO   | SiO₂  | Al₂O₃ | Fe₂O₃ |
| magnesium oxide          | 91.7% | 1.6%  | 4%    | 1.4%  | 1.3%  |

2.2. Mix proportion design

The concrete mix design and mechanical properties of C30 concrete are shown in Table 2.

| Table 2. Concrete mix ratio and mechanical properties. |
|---------------------------------|
| W/C      | Cement (kg/m³) | Water (kg/m³) | fine aggregate (kg/m³) | coarse aggregate (kg/m³) | water reducer (g) | NaCl (kg/m³) | compressive strength (MPa) | Slumps (mm) |
| 0.57     | 325            | 185            | 662                | 1228                 | 1.625           | 9.75          | 30                             | 190 |

The MPC mix ratio and mechanical properties used in the test are shown in Table 3.

| Table 3. Concrete mix ratio and mechanical properties. |
|---------------------------------|
| MgO(kg) | KH₂PO₄(kg) | Borax(kg) | Water(kg) | compressive strength(MPa) |
| 1       | 0.75       | 0.05      | 0.28       | 3h | 1d | 7d | 28d |
|         |            |           |            | 22 | 30 | 42 | 53 |

2.3. Sample preparation

Concrete size was Φ100mm×200mm. The center of the specimen was inserted with a Φ10mm steel. The overall length of the steel bar was 250mm with 150mm inside the specimen and 100mm outside the specimen, shown in figure 1. After demolded, the specimen was maintained for 28d in curing room with temperature of 20±1°C and humidity of 50±2%. The corrosion of the specimen was accelerated by electrochemical method with device shown in figure 2. The steel bar is the anode, the stainless steel is the cathode. The solution is tap water. The current for accelerating the corrosion process was 100mA. According to Faraday's law⁵, the time for corroding the steel bars is calculated when reaching to 5%, 15% and 30% of corrosion ratio. After all the specimens were corroded, parcelled by CFRP with MPC. The length of the lap part of CFRP was 100mm, shown in figure 3.

2.4. Axial compression test

Figure 4. shows the standard axial compression test device. The load rate was controlled as 0.5mm/min. The detection range was the length of 100mm in the middle of concrete.
3. Results and discussion

After corrosion of the specimen was accelerated, the accumulation of steel corrosion caused the additional tensile stress in the concrete around the steel bar, eventually leading to a smooth expansion of the concrete protection layer, as shown in figure 5. After Corroded reinforced concrete was compressed, the vertical corrosion cracks along the upper expanded rapidly. As the load continued to increase, the brittle failure of cylindrical concrete appeared and the load reached to the peak.

The damage of MPC-CFRP confined reinforced concrete columns was due to the rupture of CFRP, indicating that the length of the CFRP lap was sufficient. Figure 6. shows the CFRP fracture failure in the axial compression test.

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**Figure 1.** Schematic of reinforced concrete

**Figure 2.** Electrochemical accelerated corrosion

**Figure 3.** Schematic of package

**Figure 4.** Axial compression test

**Figure 5.** Different degree of corrosion of specimens: (a) Corrosion ratio 5%; (b) Corrosion ratio 15%; (c) Corrosion ratio 30%

**Figure 6.** Fracture failure of CFRP
The axial load-displacement curves of the reinforced concrete columns with natural corrosion and corrosion ratio of 5%, 15% and 30% are shown in figure 7.

![Graphs showing load-displacement curves](image)

**Figure 7.** Load-displacement curves of reinforced concrete columns: (a) unconfined concrete columns; (b) confined concrete columns; (c) concrete columns with different constraints

As seen from Fig. 7(a), the ultimate bearing capacity of the unconstrained reinforced concrete columns decreases with the increase of corrosion ratio. Compared with the natural corroded concrete column, the ultimate strengths of reinforced concrete columns with corrosion ratios of 5%, 15% and 30% decrease by 8.15%, 32.61% and 42.53%, respectively. In Fig. 7(b), the ultimate bearing capacity of MPC-CFRP restrained corroded concrete columns decreases with the increase of corrosion ratio. Compared with the natural corroded concrete column, the ultimate strengths of reinforced concrete columns with corrosion ratios of 5%, 15% and 30% decrease by 13.14%, 17.53% and 30.04%, respectively. Comparison with Fig. 7(a), the ultimate strengths of natural corrosion column and columns with corrosion ratios of 5%, 15% and 30% increase by 57.4%, 58.27%, 65.9%, 66.21%, respectively. Therefore, the MPC-CFRP can obviously improve the ultimate strength and ultimate displacement of the concrete column. It is because MPC-CFRP effectively constrains the expansion of the compressed concrete. Compared with the unreinforced concrete columns, the ultimate strength and ultimate displacement are obviously improved. As you can see in Fig. 7(c), the discontinuous package has a lower strength and ductility than the whole package. The compressive strength of the two-layer whole package is obviously greater than that of the one-layer whole package. The ratios of the compressive strengths of discontinuous one-layer wrapped concrete, one-layer whole wrapped concrete, two-layer whole wrapped concrete to natural corroded concrete are 2.32, 2.35, and 3.01 respectively.

4. Conclusion

1. The ultimate bearing capacity and ultimate displacement of corroded reinforced concrete columns can be obviously improved by MPC-CFRP reinforcement.
2. The increase rate of the ultimate strength of reinforced concrete columns strengthened with MPC-CFRP decreases with the increase of corrosion ratio.
3. The compressive strength of all wrapped reinforced concrete is greater than that of discontinuous wrapped reinforced concrete, which is lower than that of two-layer wrapped reinforced concrete.
Acknowledgement
The authors would like to acknowledge the financial support provided by National Key R&D Program of China (2017YFB0310100); National Natural Science Foundation of China (51678011).

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