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SHORT PROJECT NOTE

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Synthesized intervention method to prolong service life of reinforced concrete structures: ICCP-SS

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1 | INTRODUCTION

The reliable determination of the end of service life of structures actually gets a lot of attention. Considerable effort is invested in improving models for chloride penetration, carbonation, frost-thaw attack, and alkali aggregate reaction.

However, at least as important is the question how to prolong the service life of existing structures which are subject of deterioration and have lost a part of their bearing capacity due to corrosion of the reinforcing steel. In such a case, the structure can be strengthened by externally bonded reinforcement like fiber-reinforced polymer (FRP). Moreover, the corrosion process can be stopped by applying a protective measure like cathodic protection. It was wondered whether it is possible to combine strengthening and cathodic protection in one system. This could be realized if the strengthening material, which is normally carbon FRP (CFRP), bonded to the concrete with epoxy, could simultaneously be used as an anode in the cathodic protection system. A research group headed by Prof. Ji-Hua Zhu at Shenzhen University in China, showed that this is a realistic and very promising option. The researchers developed a synthesized intervention method, called ICCP-SS, where ICCP stands for impressed current cathodic protection and SS for structural strengthening.

2 | BASICS OF THE ICCP-SS

For strengthening of concrete structures often use is made of externally bonded FRP. This material consists of a large number of continuous, oriented fibers, typically embedded in a polymeric matrix. CFRPs are promising materials to fulfill a double function: on the one hand, they are characterized by high strength, low weight, and good long-term durability, so that they are suitable for strengthening. On the other hand, they have electrically conductive properties, so that they could function as well as an anode in a cathodic protection system. Carbon fiber is substantially less expensive than titanium, a typical material for ICCP. Figure 1 shows a schematic representation of the ICCP-SS system. The figure shows a part of a conventional reinforced concrete beam with steel reinforcing bars at the bottom. At the top, a carbon fiber composite is bonded to the concrete in order to strengthen the concrete member and at the same time act as an anode in the protecting system.

If the carbon fiber layer would be bonded to the concrete in the traditional way, with an epoxy resin, the system would not function well, because the combination of CFRP and epoxy resin lacks conductivity, so that the current is hindered to proceed to the reinforcement through the concrete. However, nearly a decade ago a cementitious matrix was introduced by

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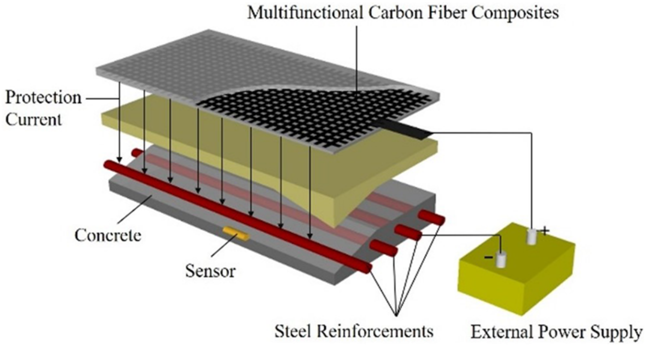

FIGURE 1 Schematic representation of the impressed current cathodic protection–structural strengthening (ICCP-SS) system

FIGURE 2 Installation of impressed current cathodic protection–structural strengthening (ICCP-SS) system on piers of the Guangzhou–Shenzhen highway

Triantaffilou et al,[1] as an alternative to FRP–epoxy resin to lower the costs and improve durability. Compared to the traditional epoxy resin, the cementitious matrix has its own advantageous characteristics, such as good electrical conductivity, high durability, simple installation, high fire resistance, and simple reversibility (i.e., to undo the repair without harming the original structure). In addition, the chemical, physical, and mechanical properties of the cementitious matrices are compatible with those of the concrete substrate. By embedding a carbon fabric mesh inside the cementitious matrix, a carbon fabric-reinforced cementitious matrix (C-FRCM) is produced, which is much better able to fulfill the pursued double function of strengthening and protecting.

3 | RESEARCH

The effectiveness of ICCP depends essentially on the selection of the anode, which governs electrical conductivity and the rate of consumption induced by a number of environmental and operational factors. Therefore, selecting the most suitable anode material and applying an appropriate current will contribute significantly to the avoidance or minimization of damage to the anode, such as excessive consumption or loss of bond with the concrete.

Tests on columns with corroded reinforcing steel, protected by the ICCP-SS system, showed that the system worked successfully with regard to both its protecting and its strengthening function (Su et al,[2] and Zhu et al,[3,4])

The performance of the CFRP anode was investigated in a simulated ICCP system with an electrode composed of 3% NaCl solution, NaOH solution, and simulated pore solution. On the one hand, the CFRP could operate in a stable way in all three solutions, and the electrochemical performance was not significantly compromised during 50 days of polarization when the applied current was as high as 6.15 A/m^2. On the other hand, the results of the CFRP tests after polarization demonstrated that the tensile strength of the CFRP decreases with increasing charge densities in the simulated ICCP system. On basis of those first tests, it was concluded that the ICCP-SS system is able to restore the bearing capacity of a structure, previously reduced by reinforcement corrosion.

Application of ICCP-SS requires substantial amounts of CFRP. For the sake of sustainability, it is important to consider as well recycling of the CFRP waste. When investigating degradation of the CFRP anode, it turned out that the main degradation mechanism was the degradation of the resin matrix. This interesting observation leads to a new recycling method for used CFRP composites. This ecofriendly recycling method enables fiber regaining under atmospheric pressure and at room temperature. Hence, this new invention effectively copes with increasing CFRP waste, by reusing it in new CFRP composites, the cost of which is much lower than that of newly produced composites, whereas the mechanical properties are the same.

4 | PILOT APPLICATION

The ICCP-SS system was installed on one of the docks of China Merchants Port and the Guangzhou–Shenzhen highway in Guangdong, China (Figure 2). After the intervention, the estimated corrosion rate was reduced from 6.5 μm/year to less than 1.4 μm/year, whereas simultaneously the load bearing capacity of the piers and beams involved increases by 30–40%. The functioning of the ICCP-SS system in this practical environment is monitored in time, by recording the corrosion current density and inspections (visual, ultrasonic, acoustic).

DATA AVAILABILITY STATEMENT

Data sharing not applicable—no new data generated.

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