The experimental study on the behavior of Coated Concretes

Lingyun Ma\textsuperscript{1,2}, Jingjing He\textsuperscript{1,2}, Yufei Sun\textsuperscript{1,2}, Shengjie Di\textsuperscript{1,2}, Ying Zhang\textsuperscript{1,2*} and Peng Huang\textsuperscript{1,2}

\textsuperscript{1}Northwest Engineering Corporation Limited, Power China, Xi’an, Shaanxi, 710065, China
\textsuperscript{2}High Slope and Geological Hazard Research & Management branch, National Energy and Hydropower Engineering Technology R&D Center, Xi’an, Shaanxi, 710065, China
\textsuperscript{*}Corresponding author’s e-mail: zhangying@nwh.cn

\textbf{Abstract.} In this paper, different waterproof materials are used to brush the concrete surface, and the influence of different coating materials on the microstructure, porosity, mechanics and durability of concrete is analysed. The results show that the frost resistance of concrete after coating treatment is improved to varying degrees, and the water absorption characteristics are reduced to varying degrees, among which the effect of modified methyl ester coating material is the most significant. The results of micro analysis show that the coating material can form a film on the surface of concrete, improve its surface microstructure and reduce the porosity of concrete.

\section*{1. Introduction}
It is inevitable that the service life of concrete structures will be reduced by the erosion of various external harmful substances [1-3]. Most of the erosion occurs through water adsorption and infiltration; for instance: Cl\textsuperscript{-}, SO\textsubscript{4}\textsuperscript{2-} and so on all enter into the concrete through water penetration, and then have destructive erosion. In addition, water penetration is also a prerequisite for the failure models of concrete such as freeze-thaw and carbonation [4]. Therefore, delaying water penetration or blocking water invasion is the key to improve the performance of concrete [5].

The surface coating treatment can form an isolation layer between the concrete and the external environment, change the surface properties of concrete, and then prevent or delay the invasion of harmful substances [6], improve the compactness of concrete. At the same time, it can also improve the sensory quality of concrete products. At present, the research in this field at home and abroad mainly focuses on the preparation methods of coating materials and the micro morphology analysis of the interface with concrete. For example, She et al. [7] combine nano-SiO\textsubscript{2} with organosilane, nano-SiO\textsubscript{2} particles disperse in water to form SiO\textsubscript{2} sol, silane functional groups hydrolyze in water to form silanol, and silanol reacts with hydroxyl groups in concrete particles to form superhydrophobic layer on the surface of concrete. He et al. [8] treated the rubber surface with KMnO\textsubscript{4} solution and NaHSO\textsubscript{3} solution, and found that the bonding strength between rubber and cement paste after surface modification was greatly improved. Zhang et al. [9] found that the wear resistance of the superhydrophobic coating first increases and then decreases with the increase of the substrate roughness, and the surface adhesion force of the sample increases with the increase of the substrate surface roughness. Song et al. [10] prepared a new type of fluorine-free superhydrophobic concrete surface protection coating, and observed its surface. It was found that the surface of the new superhydrophobic or concrete system had a square convex structure with the size of 300 \(\mu\text{m}\), and the
surface was very rough, which was composed of micron or nano particles. Yan et al. [11] analyzed the condensed phase of halogen-free polymer thermal coating on concrete surface and the infrared spectrum of condensed phase after combustion. The results show that CH$_3$ compound decomposes after 30–60min combustion of polyurethane coating A2, while the chemical composition of synthetic rubber coating B2 does not change significantly. Zhang et al. [12] studied found that composite emulsion and silane emulsion can form a dense hydrophobic layer on the surface of concrete so as to achieve waterproofing effect. However, the experimental research on the influence of coating materials on concrete performance is relatively less. Based on the above analysis, the modified methyl methacrylate coating (hereinafter referred to as modified methyl methacrylate coating), styrene acrylate coating, silane impregnated emulsion and organosilicon impregnating waterproofing agent were applied to treat the concrete surface, and the effects of different coating materials on the properties of concrete were studied, so as to provide a new way to improve the performance of concrete.

2. Experimental study

2.1. Test overview

The cement is made of P.O42.5 and fly ash is grade I. The aggregate is taken from a hydropower station project in China. The naphthalene ZB-1A is used as water reducer, DH9 is used as air entraining agent, and modified methyl methacrylate coating, styrene acrylic emulsion paint, silane impregnating waterproofing agent and organosilicon waterproofing agent are selected as coating materials. The reference concrete is C20, the impermeability grade is W6, the frost resistance grade is F50, and the mixture ratio design is shown in table 1.

| Table 1. Base concrete mix ratio |
|-------------------|-----------------|-------------|----------|-----------|-----------|
| coarse aggregate grading | water-binder ratio | fly-ash content (%) | mixing amount of ZB-1A (%) | mixing amount of DH9 (%) | sand ratio (%) |
| 50 : 50 | 0.52 | 30 | 0.7 | 0.002 | 36 |

The samples were prepared according to the mix proportion in table 1, and the standard curing time was 28 days (the temperature was 20±2°C, the humidity was more than 95%), and then the samples were placed in the laboratory environment (temperature 20±2°C, humidity greater than 50%) for 7 days. After the sample surface was completely dry, the coating materials were applied, and the drying curing time was 3 days. The surface morphology and pores of the samples were observed, and the mechanical properties and durability tests were carried out.

2.2. Effect of coating on Microstructure of concrete

The microstructure of the surface of the samples with different coating materials is analyzed. As shown in figure 1, R represents the base concrete, M represents the coating of methyl methacrylate, and ST represents the coating of styrene acrylic emulsion coating concrete. SI represents the coating of silane impregnating waterproofing agent coating concrete, and O represents the coating of silicone waterproof agent concrete. It can be seen from figure 1. that the surface of the modified methyl ester coating and styrene acrylic coating concrete has been completely covered by the coating, forming a dense layer, which significantly reduces the number of pores on the concrete surface, and can play a role in isolating the concrete from external harmful substances. However, a small number of cracks appeared on the surface of the concrete treated with styrene acrylic coating, and the uniformity of the film formation was not as good as that of the modified methyl ester coating; the surface of silane impregnated and silicone impregnated concrete also formed a film, and the small pores on the concrete surface were filled and covered by the coating, and the macro view of the sample showed a certain hydrophobicity, as shown in figure 2, the hydrophobic angle of water droplets on the surface of the specimen was large. The hydrophobic state shows that the coating has good hydrophobicity. However, the coating formed by organosilicon waterproofing agent is thin and does not form a complete film, and its hydrophobicity is relatively poor.
2.3. Effect of coating on porosity of concrete

The pore characteristic parameters and pore size distribution of the reference concrete and the surface layer of the concrete treated with different coatings (1 cm from the surface) were analyzed. The results are shown in figure 3 and table 2. The results show that the surface porosity of the coated concrete is lower than that of the reference concrete, and the pore size distribution greater than 200 nm decreases obviously. Among them, the porosity of modified methyl methacrylate material and silane material decreased by 24.9% and 20.8%, respectively, while that of styrene acrylic material and silicone waterproof material decreased by 7.78% and 12.9% respectively. It can be seen that after coating treatment, the coating penetrates into the surface of concrete by impregnation, blocking some micro holes and reducing the porosity of concrete.

| Coating type | Porosity (%) | Porosity reduction rate (%) | Median pore size (nm) | Pore size (nm) Distribution (%) |
|--------------|--------------|----------------------------|-----------------------|---------------------------------|
|              |              |                            |                       | <20    | 20~50  | 50~200 | >200   |
| R            | 18.76        | 0.00                       | 743                   | 16.82  | 8.38   | 10.20  | 64.60  |
| M            | 14.08        | 24.95                      | 64                    | 39.35  | 8.88   | 9.74   | 42.03  |
| ST           | 17.3         | 7.78                       | 622                   | 17.76  | 9.63   | 10.10  | 62.51  |
| SI           | 14.86        | 20.78                      | 409                   | 27.84  | 8.72   | 9.03   | 54.41  |
| O            | 16.34        | 12.90                      | 433                   | 26.17  | 7.46   | 7.72   | 58.65  |

2.4. Effect of coating on mechanical properties of concrete

The mechanical properties of the coated concrete were tested and analyzed. The results are shown in table 3. Compared with the reference concrete, the compressive strength, splitting tensile strength and bending strength of the coated concrete have no significant changes, and the change range of the strength index is less than 10%.

| Coating type | Compressive strength (MPa) | Splitting tensile strength (MPa) | Bending strength (MPa) |
|--------------|----------------------------|---------------------------------|------------------------|
| R            | 27.4                       | 2.10                            | 3.14                   |
2.5. Effect of coating treatment on frost resistance of concrete

The experimental study on the frost resistance of concrete after coating treatment is carried out, and the influence law of coating treatment on the frost resistance of concrete is analyzed. The results are shown in figure 4 and figure 5. The indexes of frost resistance of concrete after coating treatment are improved to varying degrees, among which the modified methyl ester coating is the most obvious, followed by silane impregnation coating, and the quality loss of 100 times of freeze-thaw cycle is less than 1%. The relative dynamic modulus of elasticity decreased by no more than 10%. In terms of microstructure, the pore size larger than 200nm has an adverse effect on the frost resistance of concrete, and reducing the number of voids in this part can improve the frost resistance of concrete. Therefore, after coating, the porosity of concrete surface area is reduced, the proportion of pore space greater than 200nm is reduced, and the frost resistance of concrete is improved.

|   | M    | 29.5 | 2.23 | 3.44 |
|---|------|------|------|------|
|   | ST   | 26.2 | 2.00 | 3.29 |
|   | SI   | 28.5 | 2.10 | 3.19 |
|   | O    | 27.9 | 2.09 | 3.05 |

![Figure 3. Pore size distribution of concrete surface treated with different coatings](image)

![Figure 4. Variation of mass loss of concrete with freeze-thaw cycles after coating treatment](image)

![Figure 5. Variation of relative dynamic elastic modulus of concrete after coating treatment with freeze-thaw cycles](image)
2.6. Influence of coating treatment on impermeability of concrete
In order to analyze the influence of coating treatment on concrete impermeability, the relative permeability coefficient method is used to test the impermeability of coated concrete. The test results are shown in figure 6.

It can be seen from figure 6 that the permeability coefficient of concrete after modified methyl ester coating treatment is reduced, which shows that the modified methyl ester coating treatment can improve the impermeability of concrete. However, the permeability coefficient of the other three kinds of coatings has no obvious change, so it has little influence on the impermeability of concrete.

2.7. Effect of coating treatment on water absorption of concrete
According to JCT 902-2002 carried out the experimental study on the influence of coating treatment on water absorption of concrete. The test results of water absorption ratio of different coating materials are shown in figure 7. After the coating treatment, the water absorption ratio of the sample is reduced to 10~30% of the reference concrete. And the modified methyl ester coating has the lowest water absorption ratio.

3. Conclusion
The results show that a dense film is formed on the surface of the concrete treated by modified methyl ester coating and styrene acrylic coating, which insulates the concrete from the outside. After silane impregnation and silicone impregnation, a transparent and thin film layer is formed on the surface of the concrete, which makes the surface of the specimen relatively smooth and has a certain hydrophobic property.

Compared with the reference concrete, the porosity of the surface layer of the coated concrete is significantly reduced. The porosity of concrete treated with modified methyl methacrylate and silane decreased by 20%.

The frost resistance of concrete after coating treatment has been improved to varying degrees, and the performance of modified methyl ester coating is the most obvious. However, the coating treatment has no significant effect on the compressive strength, splitting tensile strength and bending strength of concrete. After coating treatment, the water absorption ratio of concrete samples decreased, and the water absorption ratio of modified methyl ester coating was the lowest and reached the best.

References
[1] Boomfeld J.P., (1996) Permanent corrosion monitoring. Construction Repair, 10: 44-49.
[2] Hunkeler F., (1996) The resistivity of pore water solution a decisive parameter of rebar corrosion and repairmethods. Construction and Building Materials. 10: 381-389.
[3] Mehta P.K., (1997) Durability-critical issues for the future. Concrete International, 19: 27-33.
[4] Song H., Niu D.T., Li C.H. (2009) Carbonation test of concrete containing mineral admixtures.
[5] Yang P., Li W.H., Zhao T.J. (2012) Protective effect of surface coatings on concrete. Journal of the Chinese Ceramic Society, 40: 1613-1617.

[6] Medeiros M.H.F., Helene P. (2009) Surface treatment of reinforced concrete in marine environment: Influence on chloride diffusion coefficient and capillary water absorption. Construction and Building Materials, 23: 1476-1484.

[7] She W., Wang X., Miao C., et al. (2018) Biomimetic super hydrophobic surface of concrete: Topographic and chemical modification assembly by direct spray. Construction and Building Materials, 181: 347-357.

[8] He L., Ma Y., Liu Q., et al. (2016) Surface modification of crumb rubber and its influence on the mechanical properties of rubber-cement concrete. Construction and Building Materials, 120: 403-407.

[9] Zhang X., Mo J.L., Si Y.F., et al. (2018) How does substrate roughness affect the service life of a superhydrophobic coating. Applied Surface Science, 441: 491-499.

[10] Song J.L., Li Y.X., Xu W., et al. (2019) Inexpensive and non-fluorinated super hydrophobic concrete coating for anti-icing and anti-corrosion. Journal of Colloid and Interface Science, 541: 86-92.

[11] Yan H.N., Anil S., Aravind D., et al. (2017) Thermal decomposition and fire response of non-halogenated polymer-based thermal coatings for concrete structures. Surface and Coatings Technology, 320: 396-40.

[12] Zhang Y.L., Li S.C., Zhang W.J., et al. (2019) Preparation and mechanism of graphene oxide/isobutyltriethoxysilane composite emulsion and its effects on waterproof performance of concrete. Construction and Building Materials, 208: 343-349.