Performance Parameters of Repair Materials for Freeze – Thaw Erosion in Water Conveyance Canals

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Abstract Concrete lining slabs of long-distance water conveyance projects in northern China are susceptible to freeze – thaw erosion, which places higher requirements on the performance of repair materials for eroded areas, such as frost resistance, adhesion, coating penetration depth, water absorption ratio, and durability. Performance tests were conducted on existing repair materials, and the results showed that: XYPEX exhibits better performance compared to other materials; the high-performance ultra-nano silane impregnant has outstanding performance; and the composite coating demonstrates excellent comprehensive performance. The composite material modified with nano-SiO_2 has further improved strength and durability.

Key words Freeze – thaw erosion; Repair materials; Adhesion; Durability

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The Middle Line of the South-to-North Water Diversion Project passes through Henan Province, Hebei Province, Tianjin and Beijing, located in the temperate semi-humid zone and the East Asian monsoon climate region. Since the full-line water supply operation in 2014, due to comprehensive factors such as the natural environment and water level changes, the water conveyance lining slabs have suffered varying degrees of freeze-thaw erosion damage[1]. According to the actual project conditions, it is necessary to study the performance of repair materials.

1 Test objectives

(1) For preventive materials, silane-based, penetrating crystalline, and cycloaliphatic coating materials, indicators such as economy, environmental protection, mechanical properties, and durability are combined to conduct a comparative analysis of the advantages, disadvantages, and applicable conditions of the materials, and the optimal materials that meet the requirements are selected.

(2) This study plans to carry out material optimization for repair materials such as high-strength mortar, acrylic emulsion mortar, and epoxy mortar. For materials with relatively good short-term on-site application effects in freeze – thaw erosion repair of the Middle Route of the South-to-North Water Diversion Project, such as polymer mortar, relevant laboratory studies and performance improvement tests will be conducted.

2 Implementation of laboratory tests on preventive materials

2.1 Selection of preventive materials

(1) The active chemical substances undergo a hydration reaction with unhydrated cement particles, promote cement hydration, form cement hydration crystals, and generate a large number of crystals to fill and block pores, preventing water from entering the concrete, thereby achieving the waterproof purpose[2].

Three types of cementitious capillary crystalline waterproof materials were selected in this study, namely: X-MT cementitious capillary crystalline waterproof material, XYPEX cementitious capillary crystalline material, and high-performance special active silicon anti-carbonation sealant for hydraulic concrete.

(2) They permanently change the surface properties of the substrate through chemical reactions with the substrate, thereby providing excellent water repellency and durability.

Three types of silane impregnating protective materials were selected in this study, namely: nano small-molecule silane impregnating material, high-performance ultra-nano silane impregnant, and T90 silane impregnant.

(3) Film-forming coatings such as cycloaliphatic coating. This type of coating material has various excellent properties, and can be used to protect the concrete surfaces of water conservancy facilities such as dams and canals, and resist water scouring and erosion, and the damage of harmful substances in water to concrete.

Five types of concrete surface protective coating materials were purchased for this test, namely: decorative anti-corrosion coating material for concrete structures, polymer-modified waterproof coating, high-permeability elastic epoxy coating, emulsion-type synthetic polymer waterproof coating, and concrete protective composite coating.

2.2 Determination of performance indicators According to the characteristics of preventive materials and the project conditions, the main performance indicators to be determined include frost resistance, adhesion/tensile bond strength, coating penetration depth, and water absorption ratio.

2.3 Test methods

(1) Steps. ① Except for the coated surface and its opposite

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surface, the other four surfaces of the test piece are sealed with solvent-free epoxy coating. If there are pinholes in the epoxy coating, they should be sealed. Three coated test pieces are prepared. At the same time, three blank test pieces without impregnating coating are prepared[3]. ② The test pieces are dried at 50 ℃ for 48 h, then taken out and cooled to room temperature in an environment with a temperature of (20 ± 2) ℃ and a relative humidity of (60 ± 5)%. ③ A glass rod with a diameter of 10 mm is placed at the bottom of a flat-bottomed container. The initial mass of the test piece is weighed, then it is placed on the glass rod with the coated surface facing down. Water is injected at (20 ± 2) ℃, with the water level 1 to 2 mm higher than the glass rod. After 24 h, the test piece is taken out, wiped to a surface-dry state, and weighed. Finally, the water absorption of the test piece is calculated.

(2) Penetration depth. Before the test, the test piece is dried at 50 ℃ for 24 h, then taken out and cooled to room temperature. The test piece is split, water is sprayed on the split surface, and the depth of the non-water-absorbing area is measured. The average value of 8 to 10 measurement points is taken as the penetration depth of a single test piece, and the arithmetic average value of three test pieces is taken as the measured value of the penetration depth of the group, accurate to 0.1 mm.

(3) Adhesion/tensile bond strength. The adhesive is applied evenly on the surface of the unpainted and newly cleaned test column. During the curing period of the adhesive, the surface of the test column coated with the adhesive is bonded to the coating. After the adhesive is cured, a cutting device is used to cut through the coating to the substrate along the circumference of the test column. Then, the test assembly is immediately placed under a tensile testing machine, and the test column is carefully centered so that the tensile force can act uniformly on the test area without any distortion.

3 Test results

3.1 Test results of cementitious capillary crystalline materials According to the comparative test data (Table 1), XYPEX cementitious capillary crystalline material exhibits the best comprehensive performance among the three. In terms of penetration depth, XYPEX reaches 4.8 mm, which is superior to X-MT cementitious capillary crystalline waterproof material (4.4 mm) and high-performance special active silicon anti-carbonation sealant for hydraulic concrete (4.1 mm). This indicates that it has stronger penetration and diffusion ability inside the concrete substrate, can form a deeper protective system, and has a more prominent long-term protective effect on concrete structures. For cementitious capillary crystalline materials, all performance indicators of XYPEX are better than those of the other two types, making it more suitable for protective construction of concrete structures.

Table 1 Test results of cementitious capillary crystalline waterproof coatings

No.	Item	Performance index	Test results		
			X-MT	Hydraulic concrete	XYPEX
1	Appearance		Uniform, no caking		
2	Penetration depth//mm	–	4.4	4.1	4.8

3.2 Test results of impregnating materials such as silane and siloxane Penetration depth: all three meet the index requirement of ≥2 mm (Table 2). Among them, the penetration depth of the high-performance ultra-nano silane impregnating agent reaches 3.5 mm, which is superior to the nano small-molecule silane impregnating material (3.2 mm) and T90 silane impregnating agent (3.0 mm). This shows that it has stronger penetration and diffusion ability inside the concrete substrate, can form a deeper protective system, and has a more prominent long-term protective effect on concrete structures.

Table 2 Test results of impregnating agents such as silane and siloxane

No.	Item	Performance Index	Test results		
			Silane impregnating material	T90 silane impregnating agent	Ultra-nano silane impregnating agent
1	Appearance		Uniform color, no impurities		
2	Penetration depth//mm	≥2	3.2	3.0	3.5
3	Water absorption ratio//%	≤20	7.5	9.9	8.0

Water absorption ratio: all three materials meet the index requirement of ≤20%. The water absorption ratio of the nano small-molecule silane impregnating material is 7.5%, which is lower than that of T90 silane impregnating agent (9.9%) and high-performance ultra-nano silane impregnating agent (8.0%), while the water absorption ratio of the high-performance ultra-nano silane impregnating agent is better than that of the T90 product. Overall, the water repellency and water resistance of the three are up to standard. Among them, the nano small-molecule product has the best performance in water absorption ratio, followed by the high-performance ultra-nano product.

In conclusion, the high-performance ultra-nano silane impregnating agent is more outstanding in the core index of penetration depth, and the nano small-molecule silane impregnating material has better performance in water absorption ratio. Considering the core protective performance dimensions, the high-performance ultra-nano silane impregnating agent is more suitable for engineering scenarios with high requirements for deep penetration protection of concrete.

3.3 Intensified test To better explore the promoting effect of nanomaterials on cement-based materials and study their influence law on polymer mortar, nano-SiO_2 is added to cement in the test. After curing to the specified age, XRD and TG tests are conducted on the reaction products. The details are as follows, where group PC1 is the control group (without nano-SiO_2 added) and group PC4 is the test group.

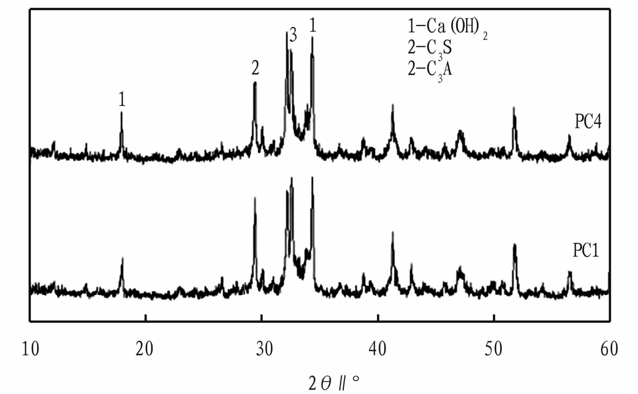

Fig. 1 XRD pattern of cement paste with nano-SiO_2 added

As can be seen from Fig. 1, compared with the blank sample group PC1, in the cement paste samples of group PC4 with nano-SiO_2 added, the diffraction peak of the hydration product $Ca(OH)_2$ is enhanced, while the diffraction peak of C_3S in the cement clinker reactants is reduced. This indicates that the introduction of nano-SiO_2 promotes the hydration rate of C_3S, generates more hydration product C-S-H, which fills the pores of the cement stone, and ensures the improvement of the strength and durability of the entire system.

3.4 Test summary Performance tests including penetration depth, adhesion, and water absorption rate are carried out on the above 3 categories, totaling 11 types of materials. For cementitious capillary crystalline materials, XYPEX exhibits better performance than other materials. For silane-based materials, considering penetration depth and water absorption rate, the high-performance ultra-nano silane impregnant has outstanding performance. For coating materials, the composite coating has good comprehensive performance. The composite material with nano-SiO_2 added has further improved strength and durability.

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Integration Curriculum Group" has been approved for the Guangxi Higher Education Teaching Reform Project.

4.1.3 Deepening the integration of industry and education. It jointly established 12 practical bases with enterprises, and collaborated on the development of 8 horizontal projects. Students have participated in more than 20 real projects of enterprises, achieving a positive interaction among "teaching – research – industry".

4.2 Problems and reflections Although the reform has achieved phased results, there are still some urgent problems to be solved: firstly, the quantity and quality of interdisciplinary teachers still need to be improved, and the integrated teaching ability of some teachers needs to be strengthened. Secondly, the depth of curriculum integration is insufficient, and some courses still exhibit a "surface integration" phenomenon, lacking substantial content integration. Thirdly, the integration of practical teaching resources is insufficient, and the sustainability and depth of school – enterprise cooperation need to be expanded.

In the future, Yulin Normal University will deepen reforms in three aspects: first, it should improve the teacher training mechanism. Through interdisciplinary training, school – enterprise joint training and other methods, teachers' integrated teaching ability could be enhanced. Secondly, it should promote the deep integration of course content and develop more interdisciplinary core courses and case resources. The third is to deepen the integration of industry and education, and jointly build industrial colleges and shared practical teaching platforms, thereby achieving dynamic adaptation of curriculum system and industry needs, and cultivating more high-quality compound smart agricultural talents for the construction of new agricultural science and rural revitalization.

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