Study and Application of Epoxy Coating in Freshwater mussels Prevention in Hydraulic Tunnels

Shifa XIA [1], Tiesheng DOU[1], Jingwei LI[1], Bo ZHAO[1], Guoyou YAO[2], Jianwei ZHOU[3]

[1] China Institute of Water Resources and Hydropower Research, Beijing, China
[2] Tsinghua University, Beijing, China
[3] Guangzhou Pumped-storage Power Plant, Guangzhou, China

ABSTRACT: Freshwater mussels are often seen growing in the south part of Yangtze River in China and are easily breeding in the concrete pipe walls in hydropower plants, leading to serious erosion, decrease in strength and impermeability, loss of durability of concrete and high maintenance cost of the powerplants. A type of epoxy coating which has a tensile strength of 15 MPa, an elongation of above 6% at break and a bonding strength of above 2.0MPa with the wet base surface, is used to prevent freshwater mussels growing on concrete walls. Laboratory results show that the density of mussels growing on the concrete samples coated with epoxy is lower than 10% of that on the controlled concrete samples without coating. Also the average number of the byssuses of the mussels on the coated walls decreased by 21.6% compared with the uncoated walls and the average adhering strength of the mussels on the coated walls decreased by 28.5%. Coating epoxy was applied in the diversion tunnel and tailrace tunnel in plant B of Guangzhou pumped-storage power plant with a total protection area of about 40,000 square meters. One year later after the coating the inspection results showed that the inner tunnel walls were smooth and almost no mussels were found on the inner tunnel walls, indicating the coating is effective.

1 INTRODUCTION

Freshwater mussels are often seen in South China. They can attach firmly to the surfaces of solid objects with their byssuses, and live on filter-feeding food such as diatom, zooplankton and organic detritus. In Korea, Japan, Australia, India and some countries in South America, the breeding of freshwater mussels is also reported. In South China, because of appropriate water velocity and environment, freshwater mussels are easy to breed on the surfaces of water transferring tunnels in hydropower station. The heavy attachment of freshwater mussels will decrease the water conveyance efficiency, result in physical and chemical erosion and affect the permeability of concrete. In addition, the freshwater mussels consumes a lot of oxygen in water and generate ammonia and nutrient salt during its growth and breeding, which will exacerbate the water quality [1].

The methods for handling freshwater mussels include physical cleaning, chemical killing and anticorrosive coating[2-4]. The effects of physical cleaning are limited, for the freshwater mussels will restore attachment shortly after being cleaned. The method of chemical killing needs a long period and may lead to water pollution, so it is not appropriate for hydropower station. The effects of anticorrosive coating is to prevent mussels from attaching and breeding. This effective method will increase the smoothness of concrete and make cleaning mussels convenient. However, so far the coating method at home and abroad is mainly to kill the shellfish using heavy metal[5], which could lead to serious water pollution, and thus is inappropriate for preventing mussels in hydraulic tunnel of hydropower station. In this study we developed an epoxy coating material which has outstanding tensile strength and elongation percentage and bonding property with wet concrete substrate. And it is non-toxic and has good mechanical properties, good construction performance and excellent prevention for freshwater mussels. From September to December in 2015, about 40 thousand square meters linings of the diversion tunnels and tailrace tunnels were protected with this type of epoxy coating, and the inspection results after a year's operation indicated that the anti-mussel effect was very good.

2 THE DEVELOPMENT OF EPOXY COATING AND PERFORMANCE TEST

2.1 Development of epoxy coating

Epoxy coating is widely used in marine and bridge engineering. Experimental results in University of Leeds indicated that the effect of epoxy coating in prevention for chloride ion corrosion and comprehensive protection of concrete was excellent. The Great Bridge Company of Japan summed up their experience in anti-erosion of bridges and concluded that the best measure for prevention of corrosion was brushing epoxy [6]. Huang Juzheng's results[7] also indicated that epoxy coating was suitable for using as the effective and durable anti-erosion coating for marine concrete structure.

In recent years, the solvent-free epoxy coating has been under the spotlight in anti-corrosion coating. Compared with traditional epoxy coating, the solvent-free epoxy coating has the following advantages, such as no pollution to environment, good brushing property on wet substrate and increase in construction efficiency by brushing thicker layer. Also no solvent evaporation occurs during consolidation and the membrane is nonporous. Jiang Xiujie [8] and Yang Xiaogang[9]] have developed solvent-free super-high-build heavy duty epoxy coatings used in marine engineering. So far there was no epoxy coating for prevention of freshwater mussels in China.

The coating should have the following properties in order to meet the requirement for prevention of freshwater mussel in hydraulic tunnels:

(1) Effect of prevention for gold mussel should be outstanding.

(2) Considering close construction environment in hydraulic tunnel, the material should be solvent-free, and can easily consolidate into membrane in humid environment.

(3) The material should be green and nontoxic, it should meet the Standard for Safety Evaluation of Drinking Water Distribution Equipment and Protective Materials（GB/T 17219-1998）and Limit of Harmful Substances in Building Waterproof Coatings（JC1066-2008）.

(4) The material should be fit for brushing on wet substrate and should have excellent bonding property with damp concrete substrate.

(5)The material should have good durability.

According to the above-mentioned requirements, we developed a new type of epoxy coating. It is mixed by special epoxy resin and excellent toughening agent, including two components: A and B. During the study, not only the performance of the material was considered, but also the anti-crack property in low temperature and construction property in humid environment and wet substrate were concerned.

2.2 Performance of Epoxy Coating

In order to verify the performance of the epoxy coating, an indoor tests were conducted. The performance of the epoxy coating material obtained by several tests is as follows:

Table2-1 Performance of Epoxy Coating

Number	Test items		Average
1	Toxicity		no
2	Surface drying time, h		≤5
3	Tensile strength, Mpa		≥15
4	Elongation at break,%		≥8
5	Bond strength，MPa	Dry	≥4.0 or failure on base
		Wet	≥2.0 or failure on base
6	Thermal compatibility	Thunderstorm cycle	pass
		Dry heat cycle	pass
7	Crack propagation temperature，℃		≤-30

It can be seen from Table 2-1 that the newly developed epoxy coating has high tensile strength, high elongation at break and high toughness. In addition, the adhesive property with concrete is excellent, even with wet concrete, the adhesive strength is preferably 2.0 MPa or more, and the compatibility with the base surface is good. In addition, the coating itself has excellent low-temperature crack resistance, and can effectively prevent the cracking of the coating itself.

3 TESTS OF PREVENTION FOR FRESHWATER MUSSELS ATTACHMENT AND ANTI-EROSION

In order to study the effects of prevention for freshwater mussels attachment and anti-erosion of epoxy coating, Yao Guoyou conducted a field test [10] explained in details as follows:

3.1 Experiment procedure

(1) Pouring the reference concrete specimen, and the concrete mixing ratio is shown in Table 3-1. The size of the specimen is 150mm × 150mm × 150mm. After the specimen was placed, it was covered with film and placed in the standard curing room, and demoulded after 24 hours, and then placed in the standard curing room for 28 days

Table 3-1 concrete mix ratio

Water-binder ratio	Sand rate (%)	Slump (cm)	Fly ash content (%)	Water - reducing agent dosage （%）	Material usage (kg/m^3)				
					water	cement	Fly ash	Sand	stone
0.55	39.0	15.5	27.0	0.5	180	239	88	698	1104

(2) Take concrete specimen out for epoxy coating, six test specimens were painted. Three of them were used to test the compressive strength and surface pore characteristics. The other three were used to test the carbonization depth. Take another six concrete specimens without coating

under the same conditions and another six concrete specimens maintained in saturated calcium hydroxide solution for contrast.

(3) All samples (except the saturated calcium hydroxide solution group) were installed in a stainless steel cage, separated by welded rods, and the distance between the specimens was 5 to 8 cm. The immersion site of the specimen is the Xizhi river of west Dongjiang River where freshwater mussels are widely growing, and the flow velocity of the river is about 0.5m / s.

(4) After 9 months of soaking, all the specimens were taken and the number of freshwater mussels attached to each specimen was counted. Statistics of each specimen was carried out in the order of the top surface (closest to the surface of the water), the bottom (farthest from the surface of water) and the side. Each side corresponds to an attachment density (unit square area on the number of freshwater mussels), take the average value of these values as the coating surface average adhesion density. At the same time observe the integrity of anti-coating, record whether there is a drum or peeling off the situation, as the assessment of durability indicators. And then take off the freshwater mussels and sand attached on the surface of each specimen with a sampling blade.

(5) All the specimens (including the specimens immersed in the saturated calcium hydroxide solution) were sent to the professional testing institute for the above test of corrosion resistance (compressive strength, surface porosity and carbonization depth). Compressive strength and depth of carbonization were done in accordance with the "Testing code for hydraulic concrete " (SL352-2006), and the surface pore characteristics were done using the mercury porcelain method, according to "mercury intrusion method and gas adsorption method of solid material pore size distribution and porosity Part 1: (GB / T 21650.1-2008 / ISO 15901-1: 2005). Note that a sample within 1 cm of the surface of the specimen after the compressive strength was taken as the mercury intrusion test sample.

(6) The above experimental results were compared and analyzed to evaluate the erosion resistance of freshwater mussels to concrete and the anti-adhesion and anti-erosion effect of epoxy coatings.

3.2 Testing results

3.2.1 Anti-adhesion

The ratios of the average adhesion density of freshwater mussels between the specimens coated with epoxy and the blank specimens at different period are shown in Table 3-2.

Table3-2 Average adhesion density of freshwater mussels on the coated specimens to controlled specimens

Type of coating	ratio of the average adhesion density		
	After 4 months	After 6 months	After 9 months
No coating	1.000	1.000	1.000
Epoxy coating	0.095	0.076	0.086

From the above table it can be seen: After brushing epoxy coating, the average adhesion density of freshwater mussels in the different test period is only 7.6% to 9.5% of the sample without coating, less than 10%, which indicating that the epoxy coating has significant effect to prevent the freshwater mussels attachment.

3.2.2 Resistance to erosion

In order to evaluate the protective effect of epoxy coating on concrete, compressive strength, porosity, average pore size and carbonization depth of the specimen with and without epoxy coating were compared at age 9 months. The test results are shown in Table 3-3.

Table 3-3 Performance of different specimen attached by freshwater mussels for 9months

Type of specimen	Compressive strength (MPa)	Porosity(%)	Average pore size (nm)	Carbonization depth (mm)
Controlled group(Saturated calcium hydroxide maintenance)	39.1	14.16	14.6	7.00
Controlled group (in river water)	30.9	18.31	19.2	9.08
Epoxy coating	27.1	14.43	17.1	0.71

As seen from Table 3-3, after immersion in the river water and the erosion of freshwater mussels, the compressive strength of the erosion group was 21% lower than that in the saturated calcium hydroxide solution, indicating that the large amount of freshwater mussels would reduce the compressive strength of the concrete. After the epoxy coating protection of the specimen, the compressive strength decreased by 12.3%, this is mainly because of the epoxy coating, blocking the freshwater mussels to erode the concrete, but also blocking the further hydration of concrete specimens.

The porosity and average pore size of the blank group in river water increased by 29.3% and 31.5%, compared with the blank group maintained in the saturated calcium hydroxide solution, which indicated that the large amount of freshwater mussels would increase the porosity and average pore size of the concrete. The porosity and average pore size of the coated epoxy coating were 21.2% and 10.9% lower than those in the blank group, which indicated that they had certain protective effect.

For the average carbonization depth, the maximum value of the erosion of blank group in river water reached 9.08mm. After brushing the epoxy coating, the depth of carbonization was less than 1.0mm, which was reduced by more than 90%. The main reason is that epoxy material in the concrete surface formed a layer of closed coating, blocked the intrusion of carbon dioxide in water.

3.3 Analysis of test results

It can be seen from the above tests that the epoxy coating has a significant effect on reducing the adhesion of freshwater mussels and the carbonization of concrete, which also has some effect on the porosity and average pore size of concrete.

4 APPLICATION OF EPOXY COATING IN GUANGZHOU PUMPED STORAGE POWER STATION PROJECT

The construction of the Guangzhou pumped storage power station was completed in 2000, and after years of operation, it was found that a large number of freshwater mussels were attached on the surface of B plant power generation tunnel. The corrosion depth of concrete by freshwater mussels was about 5mm, influencing the water supply efficiency of the diversion tunnel. In order to select the protective coating material, 18 kinds of materials including epoxy coating were chosen by the powerplant for field test comparison [10]. After a comprehensive evaluation, epoxy coating were finally chosen as the protective coating. Since September 2015, epoxy coating was used to protect the diversion tunnel and tailrace tunnel of the B power plant in the power plant. The construction period is 82 days, and the protection area is about 40,000 m^2.

4.1 Construction technology

Specific construction process is as follows：

Figure 4-1 Freshwater mussels attached on the concrete lining surface of the tunnel

(1)Base treatment: Use high-pressure water flushing to remove the freshwater mussels on the surface of the concrete lining; After clean up the freshwater mussels, brush epoxy putty to plug the hole on lining concrete surface.

Figure 4-2 holes eroded by freshwater mussels(depth about 5mm)

(2) Mix the A and B components of the epoxy coating at a ratio (A: B = 2: 1). A, B components were black and white, and were stirred before use.

(3) Scraper method is applied with wood or plastic scraper. It is recommended to scratch a thickness of 1.5-2.0mm at a time, and the interval between each scraping time is 4-12h.

Figure 4-3 Epoxy coating site construction

(4) After the coating is finished, it is necessary to cure it for a prescribed time before it put into use. Normally, the curing time is 3 days at the temperature (20 ℃), and more curing time is required when the ambient temperature is lower. During the curing period, the coating is not completely cured, it must avoid water and mechanical damage.

(5) When achieve the curing time, adhesion test was applied to epoxy protective material. Test 3 point every 2000m^2, use drawing strength test method. The average drawing strength of three points must not less than 2.0MPa, or the destruction form is lining concrete cohesion failure. The field test results show that the bonding strength between epoxy coating and concrete base surface meets the technical requirements.

Figure 4-4 The effect of epoxy coating after construction

4.2 Protective effect

In order to evaluate the anti-adhesion effect of freshwater mussels after epoxy coating was applied, underwater vehicle was used to observe the situation one year after the construction. Test results show that [11]: after applying epoxy protective coating, the tunnel wall is smooth and almost no freshwater mussels are attached to the concrete, And no surface protective materials fell off from the concrete, showing the protective effect is good.

5 CONCLUSIONS AND SUGGESTIONS

(1) The results show that the compressive strength of concrete specimen is reduced by 21%, the porosity and average pore size of concrete are increased by 29.3% and 31.5%, and the depth of concrete carbonation is increased by 29.7% after freshwater mussels attached for 9 months. It can be seen that freshwater mussels have a great negative effect on the erosion of concrete and must be given enough attention.

(2) The results show that the tensile strength of the newly developed epoxy coating is above 15MPa, the elongation at break is above 8%, and the bond strength with the wet base is above 2.0MPa, the physical and mechanical properties are excellent. The average adhesion density of the freshwater mussels on the specimen coated with epoxy coating is less than 10% of that without coating, and its carbonization depth is more than 90% lower, which indicates that the epoxy coating has a good effect on anti-adhesive of freshwater mussels and anti-erosion of concrete. In addition, the epoxy coating is suitable for construction in the wet environment, and has excellent bonding performance with the concrete base surface. It did not appear any shedding phenomenon after one year. It is suitable for using as a paint for concrete water pipe lining to prevent freshwater mussels attachment.

(3) The use of anti-adhesion coating is an effective means to reduce the adhesion of freshwater mussels and improve the durability of concrete lining of water conveyance tunnel.

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