Experimental Study on Surface Protection of Concrete Panel in Reservoir Basin of Pumped Storage Power Station in Cold Region

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Abstract: Affected by various unfavorable factors during construction and operation, concrete panels of pumped storage power stations in cold regions are prone to cracks, freeze-thaw erosion and other defects, which reduce the impermeability and durability of concrete panels. In order to effectively improve the impermeability and freezing resistance durability of concrete panels, SK monocomponent polyurea was selected for laboratory test such as tensile strength, freezing resistance, impermeability and xenon lamp weathering according to the climatic conditions in northern cold regions and the operation characteristics of pumped storage power stations. Field protection tests were put into practice on the reinforced concrete panels of the upper reservoir of Shisanling pumped storage power station, and 10 years of tracking tests were carried out. The experimental results show that SK monocomponent polyurea has good mechanical properties and long-term durability, which can play a positive role in improving the impermeability and anti-freeze durability of concrete panels. The protective effect is remarkable.

1 Preface

As a peaking power supply, the pumped storage power station can well adapt to the load changes of the power system, provide peaking and valley-filling capacity and frequency modulation, phase modulation and emergency backup services for the power grid, improve the operating conditions of thermal power and nuclear power units, and improve power supply reliability and economic benefits. With China's economic and social development, economic restructuring and the improvement of people's living standards, the power system will require more pumped storage power stations in the power grid. By the end of 2018, China had built 34 pumped storage power stations, with an installed capacity of 30025MW; There are 26 pumped storage power stations under construction, with an installed capacity of 43210MW. The 13th Five-Year Plan for Hydropower Development clearly states that the scale of pumped storage power stations will be 100000MW by 2025. China will be in a stage of vigorous development of pumped storage power stations in the current and future period ^[1].

In a pumped storage power station, the concrete panel is the impermeability body of the power station basin. At present, the design of concrete panels is mostly based on the strength design mode, which mainly considers the need of safety and applicability of structural bearing capacity (strength) under load, and seldom considers the deterioration of structural material performance and its influence on structural safety and applicability due to

environmental effects during long-term use of the structure. Practice of projects already built or under construction in the northern cold region shows that due to the influence of the special climate and hydrogeological conditions in the northern cold region, concrete panels are prone to problems such as deterioration of concrete performance, freezing and thawing, cracking, etc. During operation, and the coupling effect of cracks and freezing-thaw and other problems produces a superposition effect, which accelerates the deterioration of concrete panel performance, thus accelerating damage. In order to better solve the above problems, improve the impermeability, durability and safety of concrete panels, and prevent the concrete panel structure from being damaged, it is of great significance to carry out experimental research on the surface protection of concrete panels.

2 Definition and Characteristics of SK Monocomponent Polyurea

2.1 Definition of SK Monocomponent Polyurea [2-3]

SK monocomponent polyurea is a multifunctional monocomponent coating, which mainly contains multifunctional polymers such as silane groups, epoxy groups, urethane groups, ether groups and urea groups. It is composed of polymer prepolymer containing polyisocyanate—NCO, blocked polyamine (including aminopolyether) and other functional additives. In the anhydrous state, the system is stable. Once the barrel is

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opened for construction, polyamine is rapidly generated under the action of moisture in the air, and the polyamine rapidly reacts with isocyanate—NCO to form monocomponent polyurea.

2.2 Characteristics of SK Monocomponent Polyurea

SK monocomponent polyurea has good aging resistance, no discoloration; chemical corrosion resistance,

non-toxic; high tensile strength, great elongation, good anti-wear performance, high bonding strength with foundation concrete. The impermeability and freezing resistance effects are good; The elongation at break is still more than 50% at minus-45 DEG C; Layered construction can ensure the uniformity of coating thickness; The construction is simple, convenient and reliable ^[4]. The main mechanical properties of SK monocomponent polyurea are shown in Table 1.

Table1. Main Mechanical Properties of SK Monocomponent Polyurea

Project	Mechanical performance index	
	Type I	Type II
Tensile strength, MPa	≥ 15	≥ 20
Elongation at break,%	≥ 350	≥ 200
Tear strength, kN/m	≥ 40	≥ 60
Hardness, ShaoA	≥ 50	≥ 80
Adhesion (wet surface), MPa	≥ 2.5	≥ 2.5
Impact abrasion strength (h/ (kg/m ²))	≥ 20	≥ 25
Water absorption,%	< 5	< 5

3 Laboratory Test of SK Monocomponent Polyurea

3.1 Tensile strength and elongation at break test

The tensile strength and elongation at break of SK

monocomponent polyurea (impermeability type) under normal temperature and low temperature environment were tested by high and low temperature electronic universal testing machine, as shown in Figure 3-1. The test adopts GB/T23446 standard. The test is shown in Table 2.

Table2. SK Monocomponent Polyurea Tensile Strength and Elongation Test Results

Serial Number	Test Temperature	Test Item	Test Result (Type I)
1	23°C	Tensile strength, MPa	17.3
2		Elongation at break,%	384
3	-45°C	Tensile strength, MPa	35.2
4		Elongation at break,%	144

Table 2 shows that SK monocomponent polyurea still has good flexibility in low temperature environment, elongation at break is greater than 100%, and tensile strength is greatly improved.

3.2 The bonding strength between SK monocomponent polyurea and concrete

When SK monocomponent polyurea is used to protect the concrete surface in water conservancy and hydropower projects, the bonding strength between SK monocomponent polyurea and concrete is very important. The test results show that the bulk strength of SK hand-cured polyurea grows slowly. As SK monocomponent polyurea has a long initial setting time and can fully react with the interface agent on the concrete surface, the bonding strength between SK monocomponent polyurea and concrete is very high, and

increases with the extension of curing time. Under the premise of special interface agent, the bonding strength between SK monocomponent polyurea and wet surface concrete is greater than 2.5MPa; SK monocomponent polyurea cures better in dry condition than in humid environment. The bonding strength between polyurea and concrete is also high.

3.3 SK Monocomponent Polyurea impermeability experiment

Pour 6 hydraulic concrete standard impermeability test blocks, drill 20 mm holes in the middle of the test block after curing for 28 days, and brush polyurea with thickness ranging from 0.8to 2 mm on the surface. After curing for 15 days, a switch for applying water pressure is installed on the back water surface and is integrated with the impermeability testing machine. The applied

water pressure is 0.3-0.5 MPa.

The test results show that SK monocomponent polyurea has good impermeability. Under the action of back water pressure, blisters first appear. With the increase of back water pressure, blisters become larger and larger, and polyurea coating becomes thinner and thinner until it bursts from a weak part and suddenly shoots water at the bubble. Therefore, SK monocomponent polyurea has good impermeability and high bonding strength with concrete, but internal bubbles should be avoided as much as possible in scraping SK monocomponent polyurea.

SK Monocomponent Polyurea

Figure1. SK monocomponent polyurea impermeability test

3.4 SK monocomponent polyurea aging resistance experiment

According to the performance and application environment of SK monocomponent polyurea, this test adopts xenon lamp artificial climate aging experiment to test the aging resistance of materials.

Xenon lamp artificial climate aging test is a kind of artificial climate aging test method which uses xenon

lamp as light source to simulate and strengthen the main factors such as light, heat, air, temperature, humidity and rainfall. It is used to accelerate the aging of materials and test the light stability and aging resistance of materials. The spectrum of xenon arc lamp reaching the sample surface is very close to the light spectrum of the sun. In the experiment, the wavelength range of xenon lamp is 300~890nm, the radiation intensity is $(1000 \pm 200) \text{ W/m}^2$, the blackboard temperature is $55 \pm 3^\circ\text{C}$; the relative humidity is 60%~70%, the rainfall period is 18min and the interval for dry is 102min. The working range of the electronic universal testing machine is 0~50kN, an accuracy level of 0.5, and a tensile rate of 500mm/min.

Table 3 shows the performance changes of SK monocomponent polyurea materials during 0~1869h of xenon lamp artificial accelerated aging test. As can be seen from Table3, after accelerated test aging for 1869h, the strength of SK monocomponent polyurea after aging is only reduced by 18%, the elongation at break is reduced from 363.6% to 338.7%, and the maximum is only reduced by 8%, with a maximum reduction of only 8%. From the change rule of tensile strength of SK monocomponent polyurea xenon lamp under artificial accelerated aging shown in Figure 2 (a), the tensile strength starts to decline rapidly, and the decline trend is stable after 500h. From the change rule of elongation at break of SK monocomponent polyurea xenon lamp under artificial accelerated aging shown in Figure 2 (b), the elongation at break starts to decline rapidly, and the decline tends to be stable after 1000h. From the change of material surface, material aging also occurs mainly in the surface layer.

Table3. Artificial accelerated aging test results of SK monocomponent polyurea xenon lamp ^[5]

Ageing time T(h)	Tensile strength(MPa)	Performance change rate (%)	Elongation at break (%)	Performance change rate (%)
0	17.11	0	363.6	0
588	14.24	17	342.91	6
1369	14.14	17	335.45	8
1869	13.95	18	338.7	7

(a) The changes in tensile strength

(b) The changes in elongation at break

Figure2. Artificial accelerated aging test results of SK monocomponent polyurea xenon lamp

3.5 Experimental study on Freeze-thaw resistance

(1) Low temperature resistance test of monocomponent polyurea

In order to understand the low temperature mechanical properties of SK monocomponent polyurea, the mechanical properties of SK monocomponent polyurea (impermeability type) in low temperature environment were tested by high-low temperature electronic universal testing machine. The mechanical properties at low temperature are shown in Table 2. From the results in Table 2, it can be seen that SK monocomponent polyurea (impermeability type) still has good flexibility under low temperature environment, and the elongation at break is still greater than 100% under the extreme low temperature condition of -45°C , and the tensile strength is greatly improved, indicating that the material body has good low temperature resistance.

(2) Test of monocomponent polyurea to prevent concrete from Freeze-thaw damage

Freeze-thaw damage refers to the fatigue stress caused by freezing expansion pressure, osmotic pressure, etc. in pore water in concrete due to positive and negative alternating changes of temperature (air temperature or water level rise and fall) under saturated or wet state of hardened concrete in hydraulic structures, resulting in gradual erosion of concrete from surface to inside.

In order to understand the protective effect of SK monocomponent polyurea on concrete freeze-thaw damage, laboratory freeze-thaw tests were conducted. In the first group of frost resistance tests, $10\text{cm}\times 10\text{cm}\times 40\text{cm}$ model test blocks were used, and the concrete test block anti-freezing label was less than F50. The specimen shall be cured for more than 28 days after molding, polished around the middle by 20cm wide (see Figure 3), coated with interface agent and SK coated with polyurea (2mm thick), and placed in a quick freezing device (see Figure 4) after 20 days, and shall be conducted according to the concrete freezing resistance test procedures in the Hydraulic Concrete Test Regulations DL/T5150-2001.

Figure. 3 Freezing resistance test specimen

Figure. 4 Freeze-thaw test process

Figure.5 Specimen after 100 freeze-thaw cycles

Figure.6 Specimen after 300 freeze-thaw cycles

As can be seen from Figure.5, when freeze-thaw is performed for 100 times, the concrete that is not coated with SK monocomponent polyurea has suffered more than 50% denudation damage, and the concrete that is coated with polyurea has not suffered denudation. As can be seen from Figure.6, the concrete surface without polyurea coating has 100% denudation damage after 300 times of freeze-thaw and the denudation is relatively

deep. The concrete with polyurea coating has not denudation, which proves that the polyurea coating can resist the freeze-thaw damage of the concrete surface.

4 SK Monocomponent Polyurea Field Protection Test

In 2007, a field test was put into practice on the reinforced concrete panel of the upper reservoir of Shisanling pumped storage power station. The test scope includes three parts: underwater, water level change area and above water.

Table 4. Bonding Test Results of SK Monocomponent Polyurea (Type I) and Concrete Panel

Test Age	Average Bonding Strength (MPa)	Interface Failure
In11 days	3.10	70% was pulled away from the coating surface and 30% from the concrete surface
In2008	3.15	50% were pulled away from the concrete
In2010	3.88	100% were pulled away from the concrete
In2012	3.44	100% were pulled away from the concrete
In2014	3.37	100% were pulled away from the concrete
In2016	3.09	100% were pulled away from the concrete
In2018	3.65	100% were pulled away from the concrete

After years of follow-up inspection, it was found that SK monocomponent polyurea scraped on-site had a glossy surface and no discoloration, all cracks and tortoise cracks in the test site were well sealed, the coating surface had no cracking phenomenon, and the bonding strength with concrete was also high, the bonding strength basically did not change, and the protection effect on concrete was obvious. Practice has proved that SK hand-scraped polyurea has anti-ultraviolet performance, is still flexible at low temperature of -40°C. It can adapt to frequent changes in water level of pumped storage power stations in cold regions and low temperature environment, and can resist deformation caused by concrete cracking at low temperature without leakage.

5 Conclusion

SK monocomponent polyurea has excellent impermeability, aging resistance, freezing resistance, low temperature flexibility and great elongation. In order to understand the protective effect of SK monocomponent polyurea on concrete, a series of laboratory tests were put into practice, and field protective tests were carried out on the concrete panel of Shisanling pumped storage power station, and tracking tests were brought into practice for more than 10 years. The test results show that SK monocomponent polyurea has good mechanical properties and long-term durability, which can play a positive role in improving the impermeability and freezing resistance durability of concrete panels. The protective effect is significant. It has a wide application prospect in large-area impermeability and freezing resistance durability protection of concrete panels in cold areas.

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