Research on Application of Single Component Polyurea in Defect Treatment of Expansion Joints of Water Conveyance Structure

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Abstract: According to the operating features of aqueducts of water conveyance structures in cold regions, this paper proposed a flexible rehabilitation plan of water sealing by single component polyurea on the surface of expansion joint of an aqueduct. The author conducted a laboratory test to study the tensile strength, bond strength, impermeability, frost resistance and aging resistance of the single-component polyurea. The results showed that the single component polyurea has strong impermeability and frost resistance, excellent aging resistance, large elongation, and high viscosity with concrete. Therefore, the single-component polyurea is suitable for the defect treatment of concrete expansion joints. In a defect treatment project of an aqueduct in the North, a flexible rehabilitation plan of water sealing by single component polyurea was implemented on the defective expansion joint of an aqueduct, and the operation effect still remained good after 3 years. The flexible rehabilitation plan of water sealing is simple and reliable because it does not damage the overall structure of the concrete and is easy to be maintained.

1. Introduction

Expansion joints in water conveyance structure shall be installed for the construction requirements, or to avoid cracks that have a negative impact on the integrity of the structure due to temperature changes, concrete shrinkage or uneven settlement of the foundation.

The rubber sealing strips or copper sheets are set in the expansion joint. In the course of operation, there often occurs water leakage in expansion joints because of the broken internal water stopping material or the unstable concrete around the water-stop belts. It is a very difficult task to deal with the leakage of the internal expansion joints of the concrete structure in water conveyance buildings. At present, one commonly adopted method is to cut out the concrete around the water-stop belt of the expansion joints, reset the water-stop belt, and then recast the surrounding concrete. Another method is to conduct chemical grouting by drilling holes near the water-stop belt of the expansion joint. However, neither method can guarantee the water-stop effect of the expansion joint, and both have long construction period, high cost, and do harm to the concrete structure near the water-stop belt. There is a simply constructed and reliably effective water-stop plan which is to reset a flexible water-stop belt on the concrete surface of the expansion joint, causing no damage to the overall structure of the concrete and easy to be maintained.
2. The principle and characteristics of single-component polyurea reaction

2.1 The principle of single component polyurea reaction
Single-component polyurea is composed of polymer prepolymer containing polyisocyanate-NCO and blocked polyamine (including amino polyether), and added with other functional additives. In the anhydrous state, it has a stable structure. Once be unlocked and exposed to the moisture in the air, the polyamine quickly reacts with the isocyanate-NCO to crosslink, forming a single-component polyurea elastomer coating film with all urea bonds in the crosslinking point.

2.2 Characteristics of single-component polyurea
Single-component polyurea has the following characteristics:
(1) Chemical resistance, excellent anti-seepage effect and anti-abrasion performance;
(2) High tensile strength, high elongation, and high bond strength with foundation concrete;
(3) Good flexibility under low temperature, and it still maintains an elongation of more than 50% at -45℃, which can adapt to the operating requirements of low temperature environment in cold areas;
(4) The material is aliphatic, anti-fade and has good aging resistance;
(5) Non-toxic, so it can be used for delivery projects for drinking water;
(6) Due to the long curing time, the surface of the concrete cracks and expansion joints can be strengthened by adding a tire base fabric;
(7) The single-component polyurea has good thixotropy, and the thickness of one-time brushing on the inclined or vertical surface is about 1mm. The construction process is simple to operate.

The main mechanical properties of single-component polyurea are shown in Table 1.

| Table 1 The main performance indicators of single-component polyurea |
|---------------------------------------------------------------|
| Item performance indicators | performance indicators |
| Item Performance, MPa | ≥15 |
| Breaking Elongation, % | ≥350 |
| Tear strength, kN/m | ≥40 |
| Hardness, shore A | ≥50 |
| Adhesion (wet surface), MPa | ≥2.5 |
| Abrasion resistance(h/ (kg/m²)) | ≥20 |
| Water absorption rate, % | <5 |

3. Test Research on single component

3.1 Tensile test
The tensile test of single component polyurea adopts GB/T23446 standard. In the experiment, the high and low temperature electronic universal testing machine was used to test its tensile strength and breaking elongation under normal temperature and low temperature. The test results are shown in Table 2.

| Table 2 Test results of single-component polyurea tensile strength and elongation |
|---------------------------------------------------------------|
| Number | Test temperature | Test item | Test result |
| 1 | 23℃ | Tensile strength, MPa | 17.3 |
| 2 | 23℃ | Breaking Elongation, % | 384 |
| 3 | -45℃ | Tensile strength, MPa | 35.2 |
| 4 | -45℃ | Breaking Elongation, % | 144 |

It can be seen from Table 2 that the single-component polyurea still has good flexibility in a low-temperature environment, and its breaking elongation is greater than 100%. That is to say, the
tensile strength has greatly improved.

3.2 Bond strength test with concrete
When the single-component polyurea is used for the protection of the concrete surface in water conservancy and hydropower projects, the bond strength between the single-component polyurea and concrete is paramount important. The test results show that the single component polyurea has a long initial setting time, so it can fully chemically react with the interface agent on the concrete surface. As a result, it produces a high bond strength between the single-component polyurea and concrete, and the strength increases with the extension of the curing time. In the case of using a special interface agent, the bonding strength between the single-component polyurea and the wet concrete surface is greater than 2.5 MPa; the single-component polyurea has a good curing effect under dry conditions and in a humid environment, so does the bond strength between polyurea and concrete.

3.3 Impermeability test
The experimenter pours 6 standard impermeability test blocks made of hydraulic concrete. After curing for 28 days, he drills a round hole with a diameter of 20mm in the middle of the test block, and paint polyurea with a thickness of 0.8~2mm on the surface. After curing for 15 days, he installs a switch to apply water pressure on the back surface, and connect it with an impermeability testing machine. The applied water pressure is 0.3~0.5MPa.

The test results show that the single component polyurea has good impermeability. Under the effect of backwater pressure, bulging appeared first. As the backwater pressure increases, the bulge becomes larger and larger, and the polyurea coating becomes thinner and thinner. This trend continues until the bulge breaks from the weak part and suddenly shoots water. It can be seen that the single-component polyurea has good impermeability and high bond strength with the concrete, but during the coating of the single-component polyurea, air bubbles should be avoided as much as possible.

3.4 Aging resistance test
As for the repair and protection material for polymer, its anti-aging performance has attracted much attention. Xenon lamp artificial climate aging test is an artificial climate aging test method, which is a simulation with xenon lamp as the light source, and its main factors are light, heat, air, temperature, humidity and rainfall. This test can be used to test the light stability and aging resistance of the material. The spectrum of the xenon arc lamp reaching the surface of the sample is very close to the spectrum of the sun. In the experiment, the xenon lamp wavelength range is 300~890nm; the radiation intensity is (1000±200) W/m²; the blackboard temperature is 55±3℃; the relative humidity is 60%~70%; the rainfall period is 18 minutes, and the interval is 102 minutes. The working range of the electronic universal testing machine is 0~50kN, and the stretching rate is 500mm/min.

Table 3 shows the results of artificial accelerated aging test of single-coat breakmponent polyurea xenon lamp. From Table 3, it can be seen that after accelerated aging for 1869h, the strength of the single-component polyurea is only reduced by 18%; the elongation is reduced from 363.6% to 338.7%, and the maximum is only reduced by 8%. Judging from the changing rules of single component polyurea tensile strength, the tensile strength began to decrease rapidly, and the downward trend was stable after 500h. From the changing rules of single component polyurea breaking elongation, the breaking elongation began to decrease rapidly. But the decline tends to stabilize after 1000h. It can be seen from the changes in the surface of the material that the material aging mainly occurs on the surface layer.

| Aging time (h) | Tensile strength (MPa) | Change rate of properties (%) | Breaking Elongation (%) | Change rate of properties (%) |
|----------------|------------------------|-------------------------------|------------------------|-------------------------------|
| 0              | 17.11                  | 0                             | 363.6                  | 0                             |
### 3.5 Frost resistance test

The hardened concrete of the hydraulic structure is saturated or immersed in water. Due to the alternating change of temperature (air temperature or water level), it makes the internal pore water forms fatigue stress caused by freezing expansion pressure and osmotic pressure. This damaging phenomenon of concrete is called freeze-thaw damage, gradually eroding from the front to back.

In order to understand the protective effect of single-component polyurea on the freezing and thawing damage of concrete, an indoor antifreeze test was carried out. The first group of frost resistance test adopts 10cm×10cm×40cm model test block, and the concrete test block's frost resistance label is less than F50. After the specimen is cured for 28 days, the experimenter sands the middle of the specimen to a width of 20cm. After applying the interface agent, the experimenter scrapes the single-component polyurea (thickness 2mm), and puts it into the quick-freezing equipment after 20 days. The experiment schedule is in the line with DL/T5150-2001 in The Concrete Frost Resistance Test Procedure.

|     | 100 freeze-thaw cycles | 300 freeze-thaw cycles |
|-----|------------------------|------------------------|
| 588 | 14.24                  | 17                     |
| 1369| 14.14                  | 17                     |
| 1869| 13.95                  | 18                     |
|     | 342.91                 | 335.45                 |
|     | 6                      | 8                      |
|     | 338.7                  | 7                      |

It can be seen from Figure 1 that when the freeze-thaw cycle is 100 times, the concrete without the single-component polyurea has exhibited more than 50% of the erosion damage, and the concrete with the single-component polyurea is not eroded. When the freeze-thaw cycle is 300, the concrete surface that had not been coated with polyurea had 100% erosion damage, and the freeze-thaw erosion was deep while the concrete coated with polyurea was not eroded, which proved that the polyurea coating could resist the freeze-thaw damage on the concrete surface.

### 4. Application examples of single-component polyurea expansion joint treatment

#### 4.1 Project overview

The second-level main canal project in an irrigation area in the north was built in the 1990s. The main building of the project is a third-level building with a designed water flow of 14.54m3/s. After more than 20 years of operation, the aqueduct buildings have experienced various degrees of aging diseases. One of the main diseases is expansion joint leakage. In order to ensure the function and water-stop effect of the expansion joint of the aqueduct, a flexible surface water-stop structure which can adapt to the deformation of the expansion joint must be used for repair treatment.
4.2 Repair plan

The aqueduct expansion joint has a maximum joint width of 5cm and a maximum deformation displacement of more than 2cm. Therefore, in order to ensure the function and water-stop effects after repairing the expansion joint of the aqueduct, it is necessary to adopt a flexible water-stop structure that can adapt to large deformation. This expansion joint water-stop and repair plan uses a single-component polyurea combined with the surface water-stop structure of the U-shaped water-stop belt. Figure 2 is a schematic diagram of the surface water-stop structure of the expansion joint of the aqueduct.

The characteristics of the water-stop structure:

1. The U-shaped part of the center of the bottom water-stop belt is designed according to the deformation of the joint, which can adapt to the displacement of the aqueduct joint without causing large stress in the water stop. Figure 3 shows the installation of the water-stop belt in the expansion joint of the aqueduct;

2. U-shaped water-stop belt is protected by epoxy mortar, which can effectively delay its aging time;

3. The single-component polyurea on the surface protects the bottom water-stop belt while also acting as an effective water-stop method.

4. The selected single-component polyurea has good low-temperature flexibility, and it does not produce cracks when folded at a temperature of -45℃. Its tensile strength, tear strength and shear strength perform well at low temperatures, so it can adapt to the low temperature in cold regions surroundings.

The construction process is: cutting out the damaged concrete around the expansion joint; cutting a 15cm-wide and 4cm-deep groove along both sides of the expansion joint; leveling the bottom of the groove with epoxy mortar; installing an U-shaped water-stop belt; backfilling the surface of the water-stop belt with epoxy mortar; reserving a space for a 3cm-wide gap in the middle; backfilling with GB filler in the gap; adding the epoxy mortar surface with a composite base fabric coating of single component polyurea with a thickness of 3-4mm and a width of 30cm.

![Figure 2. Schematic diagram of the water-stop structure of the expansion joints of aqueduct surface (unit: mm)](image-url)
4.3 Repair effect

Figure 4 shows the situation after the treatment of expansion joint of the aqueduct. After more than 3 years of operation, the treatment effect remains good. The treatment scheme solves the leakage problem of the large deformation of the expansion joint of the aqueduct, and ensures the safe operation of the irrigation area project.

5. Conclusion

Single-component polyurea has excellent impermeability, aging resistance, frost resistance and low temperature flexibility, as well as a large elongation and high bond strength with concrete. At present, single component polyurea is used in the treatment of expansion joint defects in many water conveyance buildings in cold areas, and it has achieved good results and has broad application prospects.

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