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Adhesive waterproof sheeting for underground tunnels

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ABSTRUCT: At the construction of the underground structures such as subway stations, waterproof sheeting is usually used for prevention of the underground water leakage into the structures. But in many cases, the underground water penetrates into the structures through the gap between the sheeting and structures because the sheeting is not adhered to the concrete structures. We developed the adhesive waterproof sheeting which shows excellent performance to prevent the underground water leakage. Before building the underground structures, the waterproof sheeting should be set on the soil retaining wall. Then, concrete structures are built on the sheeting. After the complete solidification of the concrete, the sheeting chemically adhered to the concrete structures and no path is shown between the sheeting and structures. Therefore, the underground water doesn't leak into the structures even if the sheeting is partially damaged by any protuberances such as struts in open trench tunnels. This technology can be applied for not only open trench tunnels but also watertight NATM tunnels that are built in city underground. By using this waterproof sheeting at the construction of underground structures, water leakage troubles after construction are effectively prevented and repairing cost will be minimized.

1 INTRODUCTION

Underground structures such as subway stations are built by the open trench construction method at the subway constructions in shallow ground (Fig. 1).

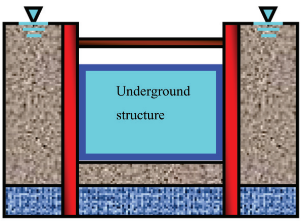

Figure 1. Open trench tunnel.

But, much expense will be estimated for repairing the water leakage and other damaged area unless the waterproof function performs. As one of the leakage prevention methods, pre-waterproofing method is executed in which underground structures are built after setting the waterproof sheet on the earth retaining wall. Even in this method, perfect prevention is difficult because of the local damage of the waterproof sheeting. When using conventional waterproof sheeting which has no adhesion to concrete, underground water will penetrates into the structures through cracks of the structures and space between the sheets and structures (Fig. 2) Then, we have developed the concrete-adhesive waterproof sheeting, which prevents the water leakage through into the structures by the chemical adhesion between sheeting and concrete even when the sheeting is partially damaged.

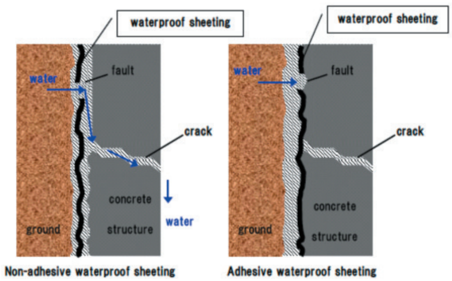

Figure 2. Mechanism of water leakage.

2 RAW MATERIALS OF THE SHEETING

At the starting the development of the concrete-adhesive waterproof sheeting, we searched the base polymers, which have the enough strength and processibility. From the conventional materials for waterproof sheeting such as PVC, rubber, EVA (ethylene vinyl acetate copolymer) and ECB, we chose the EVA as a base material. As described below, special EVA is required for the waterproof sheeting to take the adhesive property.

Secondly, we searched for the inorganic compound, which shows strong adhesive performance to fresh concrete. As the additives of concrete, blast furnace slag, coal fly ash and silica are well known. But blast furnace cement and fly ash cement shows slower hardening speed than silica cement. Therefore, we chose the silica as the adhesive component of the waterproof sheeting.

3 ADHESION MECHANISM

The strong adhesion between sheeting and fresh concrete derives from the chemical reaction of silica and cement. The sheeting contains special silica particles on its surface (Fig. 3). When fresh concrete is cast on the surface of the sheeting, the silica particles react with cement components and give firm tobermorite (a kind of calcium silicate) crystals. As the result, the sheeting and concrete structures are firmly bound during the solidification process of the cement matrix.

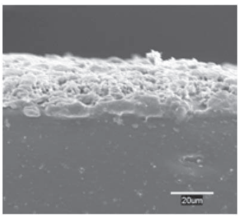

Figure 3. Cross section of surface of the sheeting.

4 CONSTRUCTION OF THE SHEETING

The waterproof sheeting for open trench tunnel has triple layer structure, which consists of adhesive layer, damage protecting layer and waterproof layer (Fig. 4). The adhesive layer consists of special EVA polymer and contains high density of special silica particles, which has strong adhesion to the concrete structures. As the damage protection layer, polyester fabric was applied in order to give strong tear strength. The waterproof layer consists of conventional EVA polymer.

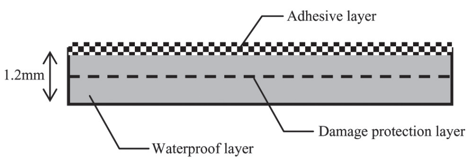

Figure 4. Waterproof sheeting for open trench tunnel.

The sheeting for the watertight NATM tunnel has two layers, adhesive layer and waterproof layer (Fig. 5). Both layers have same chemical components as the sheeting for open trench tunnel. This sheeting is thicker than the sheeting for open trench tunnel and contains no fabric because large elongation is needed to prevent the damage from the unevenness of the underground wall.

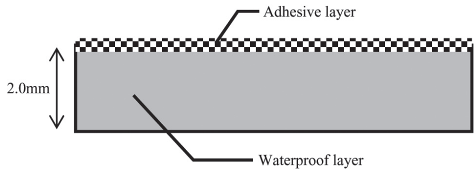

Figure 5. Waterproof sheeting for NATM tunnel.

5 INDOOR TESTS

In order to investigate the performance of the waterproof sheeting, we made some indoor tests. Those are watertightness test peeling adhesion test and physical tests.

5.1 *Test method*

5.1.1 *Watertightness test between mortar and sheeting*

The watertightness property was measured by the high pressure permeability test apparatus. Test specimen was prepared as follows. Mortar column (diameter 100 mm, height 200 mm, W/C = 50%, S/C = 2) was cast on the adhesive surface of the circle cut waterproof sheeting and cured at 20°C in saturated moisture for 7, 14, 21 and 28 days according to JIS A1132 as shown in Fig. 6. After curing, 10 mm diameter of single hole was drilled in the center of the sheeting in order to keep the water penetration

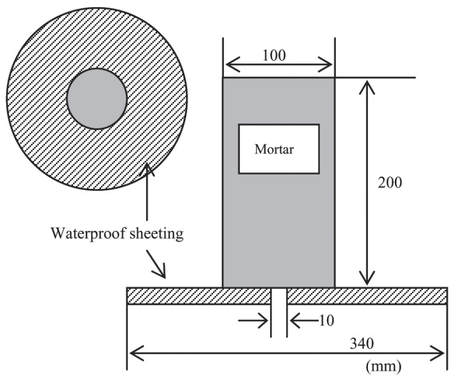

Figure 6. Size of the specimen of watertightness test.

way from the gap between the sheeting and mortar. Then the watertightness test was done as shown in Fig. 7.

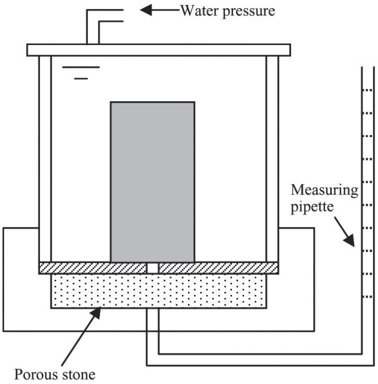

Figure 7. Concept diagram of watertightness test.

The water pressure was 0.5 MPa (water head 50 m) and the temperature was 20°C. After the water flow rate from the bottom of the pressured test tube becomes constant, the amount of the penetrated water was measured by the pipette.

5.1.2 *Peeling adhesion test*

This test was carried out as one of the adhesion tests to investigate the practical adhesion properties of the sheeting because it cannot be easily conducted at a construction site. The test specimen was prepared by casting the mortar (Portland cement, W/C = 50%, S/C = 2) directly on the adhesion layer of the sheeting followed by curing in saturated moisture (Fig. 8). The peeling adhesion tests were performed as shown in Fig. 9. The peeling speed was 50 mm/min, peeling angle was 180°, and test temperature was controlled at 20°C.

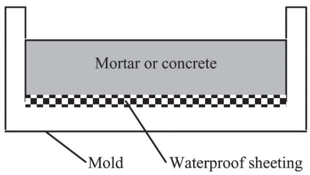

Figure 8. Preparation of peeling test specimen.

5.2 *Indoor test result*

5.2.1 *Watertightness test between mortar and sheeting*

The leaked water amount for 24 hours at 0.5 MPa of water pressure (water head 50 m) was 2.5 ml after 7 days of curing. But the leaked water amount decreased gradually along with the curing days. And after the test for 28 days cured specimen, the sheeting was peeled off the mortar in order to confirm the adhered

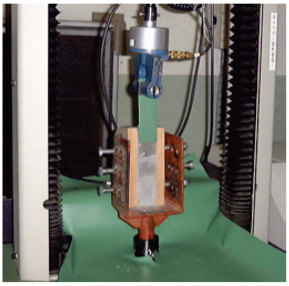

Figure 9. Peeling adhesion test.

surface of the sheeting. As a result, no trace such as waterway was detected.

Two paths are considered as waterways except the gap between the sheeting and mortar in this test. One path is inside of the sheeting and the other path is inside of the mortar. For the path inside of the sheeting, Darcy's rule can be applied, but no water was leaked through this path because no water leakage was detected in the basic watertightness test. Therefore, the water was leaked through the second path, inside of the mortar. In order to confirm the fact, we made another watertightness test in which the mortar was bound to thin aluminum sheet (0.1 mm of thickness) by caulking agent. In this test, about 2 ml of water leakage was measured in a day. From this test result, the detected water leakage at the watertightness test of the sheeting is mostly from the inside path of mortar. And in order to confirm the adhesion effect, we carried out the watertightness test for non-adhesive sheeting. As expected, more than 10^5 ml of water leakage was measured. From the tests described above, it can be concluded that this sheeting has excellent waterproof performance due to its strong adhesion to mortar even at a water pressure as high as 0.5 MPa.

5.2.2 *Peeling adhesion test*

In some peeling adhesion test in which concrete was used for the test specimen, peeling strength increased as the curing temperature increased as shown in Fig. 10.

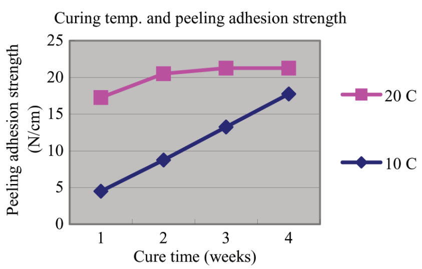

Figure 10. Curing temperature and peeling strength.

The peeling strength depends on the curing temperature. Though the peeling strength at 10°C showed lower value than that at 20°C, it increased gradually with the increase of curing days. In practical construction, the temperature of the sheeting reaches higher than that in the indoor test because a large amount of concrete is cast in one shot. Therefore, we judged that the reaction of the silica in the sheeting with concrete is accelerated and continued by the hydrolysis heat.

In order to investigate the minimum peeling adhesion strength to keep the high level of watertightness, we prepared some sheeting that have insufficient adhesion performance by changing the preparation condition. The relation between peeling adhesion strength and watertightness is shown in Fig. 11.

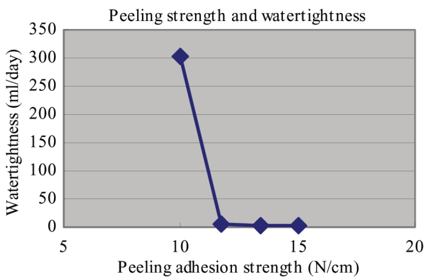

Figure 11. Peeling strength and watertightness.

As shown in Fig. 11, enough watertightness performance is maintained when the sheeting shows over 10 N/cm of peeling adhesion strength.

5.2.3 *Long-term watertightness test*

In order to clarify the time dependence performance of this sheeting, we conducted the long-term watertightness test. To make a severer test condition, ceramic balls were put on the porous stone of the watertightness test apparatus as shown in Fig. 12.

The surface of the sheeting became uneven by the balls. The watertightness tests were conducted for a period of one month. Non-adhesive sheeting was also tested as control. The water pressure was increased stepwise. Non-adhesive sheeting showed enough watertightness at 0.1 MPa of water pressure. But at higher water pressure, non-adhesive sheeting showed large amount of water leakage. The test result is shown in Fig. 13.

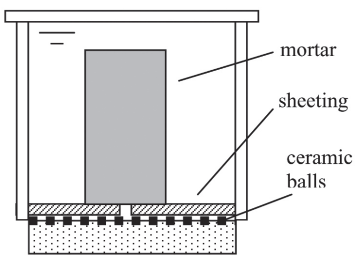

Figure 12. Watertightness test with ceramic balls.

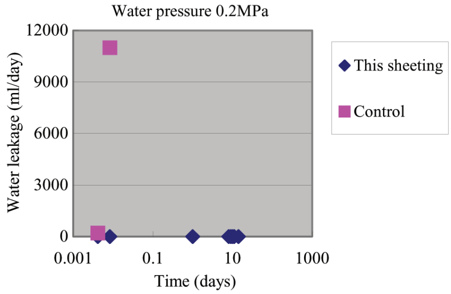

Figure 13. Long-term watertightness test result.

It means that non-adhesive sheeting is not applicable to underground constructions.

In contrast with this, the adhesive sheeting showed excellent long-term watertightness even at the 0.4 MPa of water pressure. Therefore, the adhesive sheeting is suitable for underground structures such as subway stations and tunnels.

6 CONCLUSIONS

In this paper, the newly developed waterproof sheeting was displayed. This sheeting exhibited strong chemical adhesion to the concrete, which is cast after the sheeting setting, and maintained high waterproof performance even under high water pressure. Watertightness test and peeling adhesion test were conducted to estimate the waterproof performance.

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