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PVA textiles for the prevention of concrete exfoliation of constructions

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ABSTRACT: Since the exfoliation accidents of tunnel lining concrete in 1990's, reinforcement method of concrete constructions has been studied in Japan. In recent years, the textile adhesion reinforcement method of constructions has been developed. High elastic modulus textiles are patched with resins such as epoxy and acrylic on the concrete surface without using heavy machines. Though aramid fiber is widely used in this method as reinforcing textiles, less expensive fibers has been requested in the construction field. So we tried to apply the polyvinyl alcohol (PVA) fibers to this method. We made the punching share test to estimate reinforcement performance of PVA fabric. The exfoliation strength of PVA woven fabric was 3.5~5.0 N/mm which was as strong as that of aramid fabric. According to the calculation, PVA woven fabric is possible to prevent exfoliation of concrete piece of 1 m width and 15 m length in the tunnel. Then, we carried out a practical test in the Rokko tunnel of the Shinkansen. After the test execution, no wrinkle and no swell were detected and the PVA woven fabric followed the unevenness effectively. With regard to the cost of the reinforcement fabrics, PVA woven fabric is estimated to be 40% less expensive than aramid fabric on the raw material cost basis.

1 INTRODUCTION

Since 1990's, the textile adhesion reinforcement method of concrete constructions has been studied in Japan. In this method, high elastic modulus textile is patched with epoxy or acrylic resin on the surface of lining concrete polished by sanding machine as shown in Figure 1. The textile is usually made of aramid fiber or carbon fiber. The execution of the reinforcement is easy because heavy industrial machines are unnecessary. Therefore this method attracts attention for exfoliation prevention of concrete structure such as railway tunnels.

In the electrification railway tunnels, carbon fiber is not suitable for the reinforcement textile because of its electro conductivity. Therefore aramid fiber is used for the tunnels, but aramid fiber is expensive. So, less expensive fibers have been requested in this field. We tried to apply the Polyvinyl Alcohol (PVA) fibers to this method.

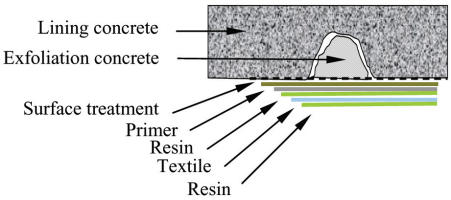

Figure 1. The outline of textile adhesion method of constructions.

2 SELECTION OF MATERIALS

2.1 *Selection of fiber*

From conventional synthetic fibers such as polyester, nylon, PVA and rayon, we chose the PVA fiber for the reinforcement fabric because PVA has excellent alkali resistance and few dimension changes compared with other fibers.

2.2 *Selection of resin*

For the textile adhesion reinforcement method of construction, there are some suitable resins such as epoxy resin, unsaturated polyester, vinyl ester, and acrylic resin. In these resins, we used the acrylic resin because of its alkali resistance and easy adjustability of hardening time compared with the other resins. Furthermore, its small hardening shrinkage is suitable for this reinforce method.

3 INDOOR TEST

We examined an adhesion strength test, punching shear test, and the tension test with PVA textile and acrylic resin.

3.1 *The adhesion strength test*

Concrete blocks of 400 mm length, 600 mm width and 50 mm height were prepared as test pieces. After polishing the surface of the concrete by sanding machine, acrylic primer resin (0.25 kg/m^2) was coated on the surface. Then PVA textile was patched on the surface with acrylic resin (1 kg/m^2). After 2 hours and 168 hours, adhesion strength was measured by detachment testing machine as shown in Figure 2. 2 hours means the period from the end of the execution to the first train and 168 hours means the complete hardening time of the resin.

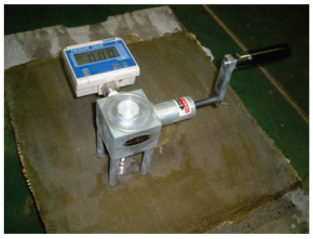

Figure 2. The adhesion strength test.

In general, the concrete surface is wet in tunnels. Therefore wet strength was also measured with test pieces that were dipped in water more than 24 hours before the adhesion strength test.

3.2 *The punching shear test*

The size of concrete test pieces is 400 mm length, 600 mm width and 50 mm height with a 100 mm diameter core hole at the center of the piece. Both dry and wet test pieces were prepared same as the adhesion strength test.

After 3 days of aging, test load was added in the core hole as shown in Figure 3 and the exfoliation circumference was measured every 0.5 kN of the increasing load. From the test result shown in Figure 4, we defined the exfoliation strength as the slope of the straight approximation of the load against exfoliation circumference.

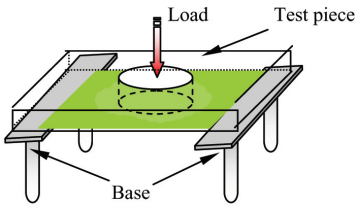

Figure 3. The punching shear test.

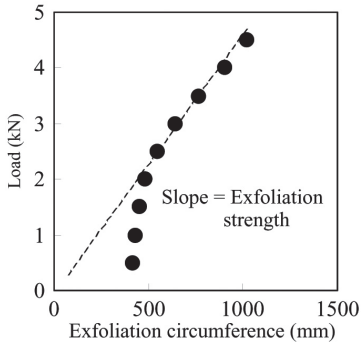

Figure 4. The exfoliation strength.

3.3 *The tensile test*

Composite (FRP) sheets are prepared with PVA textile and acrylic resin for the tensile test. Tensile strength and elastic modulus of the composite were measured.

4 RESULTS AND DISCUSSION OF INDOOR TEST

4.1 *The adhesion strength test*

As shown Table 1, adhesion strength after 2 hours was almost same value as 168 hours curing sample. And dry strength and wet strength were also same. And as shown in Figure 5, the concrete surface was destroyed while the FRP layer was not destroyed at the exfoliation.

Table 1. The adhesion strength in dry and wet state.

State	Aging time	
	2 hours	168 hours
Dry	4–5 N/mm^2	4–5 N/mm^2
Wet	4–5 N/mm^2	4–5 N/mm^2

Figure 5. The exfoliation state in attachment side.

From these test results, we concluded that 2 hours aging time was enough to get required adhesion strength and the acrylic resin is suitable for the practical executions.

4.2 *The punching shear test*

Figure 6 shows the relationship between the composite sheet elastic modulus and exfoliation strength. When the PVA textiles those have elastic modulus of less than 2.0 kN/mm^2 were used, the exfoliation strength showed less than 3.0 kN/mm and cracks occurred in the fabric at the punching test as shown in Figure 7. On the other hand, high tenacity PVA textiles those have elastic modulus more than 2.0 kN/mm^2 showed the exfoliation strength of 3.5–5.0 N/mm. This strength was as high as that of aramid textile. Furthermore, in the wet condition the exfoliation strength showed the same value as in dry condition.

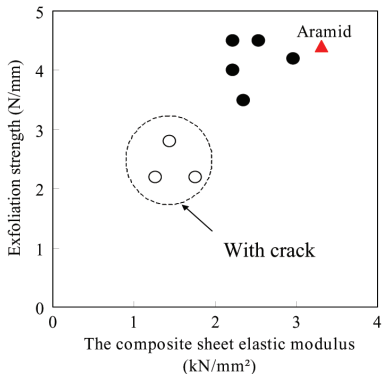

Figure 6. Relationships between the composite sheet elastic modulus and the exfoliation strength.

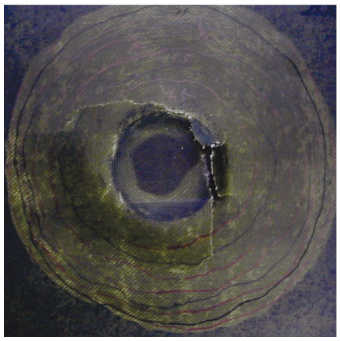

Figure 7. The composite sheet crack.

How much exfoliation strength is needed to prevent the concrete drop accident in cold jointed surface of the constructions? We calculated on the assumption that concrete was 1m of width, 15 m of length and 45 degrees of angle in a tunnel and concluded that 3.5 N/mm of exfoliation strength is needed. So we judged that high tenacity PVA textile could be applied to the textile adhesion reinforcement method of constructions.

We also considered the cover factor of the fabrics that influences the exfoliation strength. The cover factor is the area ratio of the fibers in a unit area of cloth. When the cover factor is too high, the acrylic resin cannot penetrate into the fabric in general. But as shown in Figure 8, even when the cover factor was 100%, the exfoliation strength showed larger than 3.5 N/mm. This reason is considered that PVA fiber get wet easily with the acrylic resin compared with the other fibers.

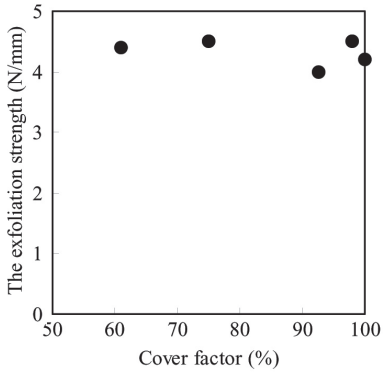

Figure 8. Relationships between the cover factor and the exfoliation strength.

5 PRACTICAL TEST

We carried out a workability test and an adhesion strength test in the Rokko tunnel of the Shinkansen.

5.1 *Workability test*

The high tenacity PVA textile (the composite sheet elastic modulus: 2.3 kN/mm^2) and aramid textile (the composite sheet elastic modulus: 3.3 kN/mm^2) were used for the test. The fabric size was 1m width and 1 m length. Two days were needed for the complete test. At the first day, surface treatment, the acrylic resin primer coating (0.25 kg/m^2), and unevenness modification were performed, and in the next day, the textile were patched with acrylic resin (1 kg/m^2) and the workability (unevenness following, wrinkle, and swell) was investigated.

5.2 *The adhesion strength test*

The test pieces (the concrete of 400 mm length, 600 mm width and 50 mm height) were aged more than 1 day in the Rokko tunnel. The acrylic primer resin (0.25 kg/m^2) was coated on the surface of the test piece after polished by sanding machine. Then PVA textile was patched on the surface of the test piece with acrylic resin (1 kg/m^2). After 2 hours and 168

hours, the adhesion strength was measured by detachment testing machine.

6 RESULTS AND DISCUSSION IN PRACTICAL TEST

6.1 *Workability test*

When the PVA textile was patched with acrylic resin, no wrinkle and no swell were detected. And it was confirmed that the PVA fabric followed the unevenness effectively because of the low stiffness of the PVA textile by visual observation. Figure 9 shows the appearance of workability test.

Figure 9. The situation of workability test.

6.2 *The adhesion strength test*

The adhesion strength showed the same performance (4–5 N/mm^2) as indoor test. As for the aging time, large difference was not detected between 2 hours aging and 168 hours aging. And the surface concrete was destroyed while the textile and resin layer was not destroyed. The adhesion strength seemed to reach enough level in 2 hours.

7 COST OF THE PVA FABRIC

With regard to the cost of the reinforcement fabric, PVA fabric is estimated to be about 40% less expensive than aramid fabric on the raw material cost basis. By using the PVA fabric as a reinforcement material, excellent performance is expected as aramid fabric at a reduced construction cost.

8 APPLICATION OF PVA NONWOVEN

To reduce the construction cost further, we investigated to apply PVA nonwoven to the textile adhesion reinforcement method of construction. A needle-punched PVA nonwoven (120 g/m^2) was estimated in the punching share test.

At the test, cracks were caused in the nonwoven at the load of 0.4 kN and the exfoliation strength was 0.5N/mm. Though it isn't enough to the tunnel concrete reinforcement, it seems to be applied for the reinforcement of back surface of the elevated bridges to prevent exfoliation of the surface concrete. We are planning to make further investigations of the PVA nonwoven reinforced method.

9 CONCLUSION

From the indoor test and the practical test, we concluded that the high tenacity PVA textile could be applied to the textile adhesion reinforcement method of constructions such as tunnels. Important results are summarized below.

- The acrylic resin gave the sufficient adhesion strength only in 2 hours in both dry and wet conditions at the adhesion strength test.
- The exfoliation strength of the high tenacity PVA textile, its modulus is more than 2.0 kN/mm^2, showed 3.5–5.0 N/mm in both dry and wet condition. This was as large as that of aramid textile.
- The high tenacity PVA fabric, which shows the exfoliation strength of 3.5 N/mm, had a potential to prevent the exfoliation of a tunnel concrete of 1 m width, 15 m length and 45 degrees of angle.
- The exfoliation strength of PVA fabric was not influenced by the cover factor.
- As for the cost, PVA fabric was estimated to be about 40% less expensive than aramid fabric.
- At the practical test, the PVA fabric showed the excellent workability and same adhesion strength as indoor test. The PVA textile could be applied to the textile adhesion reinforcement method of constructions.
- A PVA nonwoven showed 0.5 N/mm of exfoliation strength and 0.4 kN of bearing load. It seems to be applied for the reinforcement of back surface of the elevated bridges to prevent exfoliation of the surface concrete.

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