Experimental Study on Shear Performance of Interface between Polyvinyl Alcohol Fiber Engineered Cementations Composite (PVA-ECC) and Concrete

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Abstract. In order to optimize the shear resistance of polyvinyl alcohol fiber cement-based composites (pva-ecc). In this paper, four specimens with different roughness interfaces between pva-ecc and old concrete are tested and studied. Based on the uniaxial compression test, the shear strength of four interface specimens and their interface failure types are obtained. According to the test data, the ratios of the shear strength of the four specimens to the strength of the whole specimen are 18.95%, 27.27%, 45.48% and 92.2% respectively.

Keywords. PVA-ECC; Shear strength; Interface; Concrete

1. Introduction

At present, concrete structure is still the most basic building material with the largest amount used in China's construction [1]. For example, under the combined action of natural environment and human factors, ports, sea-crossing Bridges, civil buildings, etc. show different degrees of aging, deterioration and damage [2-3]. Even some newly-built concrete structures, due to diseases and defects such as honeycomb and voids, may crack and fall off a large area in a short period of time [4], which are in urgent need of repair and reinforcement.

When cement-based materials are used for reinforcement and repair of in-service reinforced concrete structures, the bond performance between the repair materials and the existing concrete is the key to ensure that the two form a whole and work together [5]. The bonding surface of the repair material and the existing concrete is a weak link [6]. Failure often occurs at the bonding surface of the two materials. Its main forms are as follows: Firstly, when the tensile stress perpendicular to the bonding surface is large, the bonding surface produces tensile failure; Secondly, when the shear stress parallel to the bonding surface is large, sliding along the bonding surface occurs and shear failure occurs; Thirdly, both of the former [7]. How to enhance the shear resistance of the repair material to the existing concrete bonding surface is the key to improve the repair effect [8]. At present, domestic and foreign researches on the mechanical properties of PVA-ECC and existing concrete bonding surface are few. Therefore, it is necessary to carry out relevant researches on the shear properties of PVA-ECC and existing concrete bonding surface.

This paper intends to conduct experimental research on four bond specimens with different interface roughness, so as to obtain the influence law of different interface roughness on the binding shear strength of
PVA-ECC and existing solidified soil and the shear performance parameters, and provide reference for later tests and practical projects.

2. The experiment

2.1 Material Performance

The materials used for the specimens were ordinary Portland cement P.O42.5, Ordinary River sand with a maximum particle size of 5mm, crushed stone with a particle size of 5-20mm and tap water. The 28-day uniaxial compressive strength of concrete is 35.1 MPa. The concrete composition is show in Table 1 and the PVA-ECC mixing ratio is show in Table 2.

| Table 1. concrete composition |
|-------------------------------|
| Cement (kg/m³) | Sand (kg/m³) | Stone (kg/m³) | Water (kg/m³) | water cement ratio | sand ratio |
|----------------|-------------|---------------|--------------|------------------|-------------|
| 407            | 640         | 1138          | 215          | 0.53             | 0.36        |

| Table 2. PVA-ECC mixing ratio |
|-------------------------------|
| Cement (kg/m³) | Coal Ash (kg/m³) | Quartz Sand (kg/m³) | Water (kg/m³) | PVA (kg/m³) | water cement ratio |
|----------------|-----------------|-----------------|--------------|-------------|------------------|
| 550            | 650             | 550             | 301          | 26          | 0.55             |

2.2 Specimen preparation

By referring to the shear properties test literature of the old and new concrete bond performance tests, it can be seen that z-shaped structural specimens are often used to carry out relevant tests in order to make the stress distribution on the old and new concrete bond surface more uniform and facilitate loading. Therefore, in order to study the shear performance of the bonding surface between PVA-ECC and old concrete, z-type specimens were used for the shear performance test of the bonding surface. The specific form and size of the specimens are shown in Figure 1.

![Figure 1. Diagram of Z-bond specimen](image)

PVA-ECC specimen preparation and maintenance of PVA-ECC using in situ conservation, to 1.5 m/s speed mixer and stir 60 s, makes the aggregate fully mixing, and then add in the 30 s, continue to cement mixing experiment closed to prevent dust into the and raw material loss, then add water and water reducing agent and stir 60 s, at this time under the condition of not cutting mixer power, stir and add PVA fiber, for all materials to join after mixing, stirring 120 s. After pouring, the specimen is formed within the mold for 24h and the mold is removed, and maintained under standard conditions for 28d. During the curing period, water is sprayed to keep the specimen moist.

The specific manufacturing process of Z-type specimens is as follows:
(1) Prepare old concrete blocks. The pre-made concrete test blocks were cut into 150mm×100mm×75mm blocks to conduct shear performance tests on the bonding surface in various interface treatment modes. The replacement test blocks were shown in Figure 2, and the bonding surface area was a square of 100mm×100mm.

![Figure 2. Photos of concrete blocks](image)

(2) The old concrete surface shall be treated. According to the commonly used concrete interface treatment methods in engineering, the old concrete surface treatment methods or interface treatment types can be divided into four categories, specifically as follows. The appearance of interface treatment is shown in Figure 3.

① type I interface: Steel brush will float ash of the old concrete surface is brushed, and clear water is rinsed clean, this type surface smoother;

② type II interface: Chisel gently with chisel of old concrete surface by hand, to remove surface relatively loose mortar, with a steel brush to float ash, and then rinse off with clear water, the type with a little degree of uneven surface;

③ type III interface: The old concrete surface with chisels chisel to loose coarse aggregate and mortar, steel brush to float ash, reoccupy balloon blowing off the surface, and then rinse off with clear water, this type are obvious uneven surface;

④ type IV interface: Groove method to deal with the old concrete surface, with a small stone cutting machine, in the old concrete surface according to certain interval cutting depth, cutting slot size here is: 20 mm wide, deep 10 mm. The main reason for adopting this method is that the interface of hand-gouging treatment is easy to generate cracks and local damages on the concrete surface, while the groove rule is easy to control the construction quality, so that the roughness uniformity of the bonding surface is good. In addition, more PVA-ECC can be entered into the trench during the preparation of specimens, thus playing a greater role in the shear performance of the bonding surface.

![Surface of type I and II](image)
(3) Average sand pouring method is adopted to evaluate the roughness of the old concrete surface. Average sand pouring method is a relatively simple evaluation method widely used in experimental research. The specific process of evaluation is: firstly, the surface of the treated concrete is placed upward, and four pieces of plastic board are used to surround it all around, so that the surface of the plastic board is flush with the highest point of the treated surface. Then standard sand is poured onto the surface to flatten it with the top of the plastic sheet. Finally, all the standard sand on the treatment surface was poured into the measuring cylinder, and its volume was measured, and the roughness of the treatment surface was represented by the average sand pouring depth. The average sand pouring depth of the treatment surface was calculated by Formula (1), through which the roughness of the four types of treatment surface could be calculated. Since there will be a certain number of specimens with each treatment surface, the roughness results are calculated by means of statistical theory. Therefore, according to the number of specimens prepared in this test, the roughness of the four treatment surfaces is shown in Table 3.

Averages and depth $h$ (mm) =

$$\frac{\text{Standard sand volume}(\text{mm}^3)}{\text{Cross section area of the specimen}(\text{mm}^2)}$$

(1)

### Table 3. Results of roughness of different surfaces

| Specimen type | Number of Sample | Mean sand depth (mm) |
|---------------|------------------|----------------------|
| I             | 11               | 0                    |
| II            | 18               | 1.43                 |
| III           | 18               | 2.61                 |
| IV            | 6                | 4                    |

(4) Cast the Z-bond specimen. First, soak the old concrete block in water for about 12 hours, take it out and put it in a dry and ventilated place, so that the surface is in a moist state without any clear water. Then put the mold on the vibration table after brushing oil, and put the old concrete block in the corresponding position; Then the PVA-ECC and the new concrete used for filling were mixed and poured into the mold, and the specimen was formed after vibration for 20–30s. During vibration, the old concrete block was clamped with an instrument, so that the bonding surface was at the position of the central axis when the specimen was formed.

(5) Specimen curing. Due to the lateral bond between PVA-ECC and old concrete, and the initial strength of the bonding surface is relatively low, the specimen is removed after 36–48 hours after molding and placed in the room. After watering, the specimen is covered with plastic cloth for curing (room temperature $20\pm 2^\circ\text{C}$, relative humidity above 95%) until the age of 28 days for testing.
2.3 Test Process
In this test, in addition to the shear strength of the bonding surface, the shear stress-slip curve of the bonding surface should be obtained. Therefore, before the test, the fixture (Figure 4) was glued to the corresponding positions on both sides of the middle height of the bonding surface with 502 glue, and then the digital indicator was fixed to measure the relative displacement of the two parts.

![Figure 4. Photos of fixture](image)

In the test, 300kN electro-hydraulic servo universal testing machine was used for loading. First, a steel pad of 100mm×100mm×10mm was placed on the support of the testing machine. The Z-type specimen was placed in a stable pair. Then start the testing machine. When the compression head and the test piece are about to contact, adjust the test piece to keep the bonding surface consistent with the loaded center line. Finally, the specimens were continuously and uniformly loaded at a speed of 0.5kN/min until the specimens were destroyed, and the load and displacement data were collected respectively.

3. Test Results and Analysis

3.1 Test Phenomena and Failure Characteristics
This test uses 300kN electro-hydraulic servo universal testing machine to load specimen until destruction, during the trial, cracks appear at the top of the bonding surface first, and then along the bond face downward extension, to final destruction, failure surface occurred at the bonding surface, as shown in Figure 5, indicating that PVA-ECC and old concrete bonding surface is a weak link.

![Figure 5. Failure modes of bonding specimens](image)

According to experimental results, the damage form of four kinds of interface approach are as follows: failure surface of type I interface is relatively smooth, and only a small amount of PVA-ECC is at the old concrete surface. The cementing action mainly comes from cementation force and the friction between PVA - ECC and concrete, which is lower. when the specimen of type II interface damaged, there was thicker PVA-ECC on the coarse aggregate of old concrete, which showed that the hardened cement mortar was cut at these locations, but no aggregate was cut. In addition to the bonding force and friction force, there is also mechanical bite force, so the bonding force is slightly higher III damage, when the type of interview, bonding surface in addition to the hardening of cement mortar were cut, is also the old concrete surface, individual aggregate was cut out some place have a hardening of the PVA-ECC adhesion,
can see the obvious fiber fracture phenomenon; At this time, the bond should also contain a small part of the aggregate and the shear action of PVA-ECC, so the bond is high. The groove on the interface of type IV is filled completely by PVA-ECC. When the interface is destroyed, PVA-ECC is cut along the bonding surface, and the damage surface is flat. At this time, the cementing action is basically provided by the shear ability of PVA-ECC, so the cementing force is obviously improved. Failure surfaces of all types of specimens are shown in Figure 6.

3.2 Test results and analysis
In this paper, the shear strength test results of all types of bond specimens and concrete specimens as a whole are statistically analyzed, and the relevant parameters obtained are shown in Table 4, where the mean of sand pouring depth is the average of all samples of each type of specimen.

According to the test results obtained in Table 4, the average shear strength of all types of specimens was compared, as shown in Figure 6. Since type I–III interface an interface roughness handling are artificial cut wool processing, the same way, the first three types of specimens are discussed. Can be seen from the Figure 6, type I–III sample, with the increase of interface roughness of the bonding shear strength to rise; type III that the bonding shear strength of the highest type of interface, this is because the type III make part of the old concrete surface processing methods of coarse aggregate is outstanding in the slurry around, increased the mechanical bite, and bonded contact area, as well as a few aggregate and PVA-ECC in shear, and improve the cohesive force; type II interview a bonding shear strength than I type of interview increased by 43.9%, while type III interview than II parts increased by 66.7%, a 140% increase over the I type, sample. It can be seen that the interface roughness has a significant influence on the bonding shear strength of PVA-ECC to old concrete. Therefore, before PVA-ECC is bonded to old concrete, the bonding surface must be roughened and the roughness should reach a certain level.

![Failure surfaces](image)

(a) Failure surface of type I (b) Failure surface of type II

(c) Failure surface of type III (d) Failure surface of type IV

**Figure 6.** Failure surfaces of each type of specimen

| Type | Sample number | Mean sand depth(mm) | Mean shear strength/MPa | standard deviation/MPa | variation coefficient |
|------|---------------|---------------------|-------------------------|------------------------|----------------------|
| I    | 11            | -                   | 0.865                   | 0.244                  | 0.282                |
| II   | 18            | 1.43                | 1.245                   | 0.689                  | 0.554                |
| III  | 18            | 2.61                | 2.076                   | 0.976                  | 0.470                |
| IV   | 6             | 4                   | 4.209                   | 0.697                  | 0.166                |
| Concrete | 6   | -                   | 4.565                   | 0.612                  | 0.134                |

**Table 4.** Results of shear strength of specimens
And, as can be seen from Figure 7, a shear strength significantly increased in type IV interface, and the shear strength of type IV interface increased higher than type III surface by 102.7%. As mentioned earlier, type IV interface due to cut groove on the surface, PVA-ECC embedded groove, the effect on the bonding shear force is mainly composed of PVA-ECC, and the bonding interface stress is slightly different from type I–III interface, which can be thought to belong to material stress. Therefore, the shear strength of type IV has improved significantly.

![Figure 7. Comparison of shear strength of specimens](image)

### 4. Conclusion

1. The selection of PVA-ECC and old z-type concrete specimens is reasonable, which can make the bonding surface uniformly stressed, avoid large bending stress and stress concentration, and the test results are reliable.

2. Based on the tests of Z-type specimens with different roughness, it is clear that the failure occurred at the interface, and the interface roughness has significant effect on the interface shear strength of PVA-ECC and old concrete. Therefore, the interface must be roughened before PVA-ECC used to repair concrete, and the roughness should reach a certain level.

3. After the surface treated by grooving, the groove is filled by PVA-ECC to contribute shear performance, and the shear strength of interface is greatly improved. The proportion of shear strength of type I–IV interface to that of concrete shear strength were 18.95%, 27.27%, 45.48%, 92.20% respectively. Therefore, when the old concrete structure need to be strengthened, the position bearing large shear force can be considered to cut grooves on the interface.

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