Shear Performance of Interface between Polyvinyl Alcohol Fiber Engineered Cementations Composite (PVA-ECC) and Concrete: Analysis and Parametric Study

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Abstract. In this paper, the shear properties of the interface between polyvinyl alcohol fiber cement-based composites (pva-ecc) and concrete with different roughness are studied. The test results show that: 1. Z-type interface can effectively improve the shear performance of pva-ecc and old concrete; 2. With the increase of roughness, the slip peak value increases, and the horizontal extension section under failure shear stress is also longer; 3. The shear strength of the four types of interfaces is directly proportional to their roughness, but lower than the shear strength of the concrete itself.

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

1. Introduction

Due to the effects of natural and man-made environment, a large number of concrete structures in China, such as ports, docks, sea-crossing Bridges and civil buildings, have been aging, deteriorating and damaged to varying degrees [1-2]; At present, there are some newly built concrete structures, even crack, large area falling off and other phenomena, which are caused by honeycomb, cavity and other defects. These problems are urgently solved.

We usually use cement-based materials to strengthen and repair existing reinforced concrete structures [3], and the bonding performance of repair materials and existing concrete affects the overall performance, which is the key to work together [4]. The bonding surface of the repaired material and the existing concrete is a fragile interface. The reinforcement effect of the structure is affected by the tensile strength, shear strength and other mechanical properties of the bonding surface [5]. The bonding surface of repaired materials and old concrete is not only subjected to uncoordinated dry shrinkage deformation and temperature deformation, but also subjected to tensile stress and shear stress. Therefore, the following failure forms often occur at the interface of repaired materials and old concrete. Firstly, when the tensile stress perpendicular to the interface is large, the interface produces tensile failure. Secondly, when the shear stress parallel to the interface is large, sliding along the interface and shear failure occur. Thirdly, the both of them above. Therefore, the key to improve the repair effect is how to enhance the shear resistance of the repair material to the existing concrete bonding surface. At present, domestic and foreign research on the mechanical properties of polyvinyl alcohol fiber engineered cementations composite (PVA-ECC) and...
existing concrete bonding surface is relatively few, therefore, it is necessary for us to carry out more research on the shear properties of PVA-ECC and existing concrete bonding surface [6-7].

According to the research results on the shear performance of the new and old concrete interface, it is clear that increasing the roughness of bond surface can effectively improve the mechanical bite force of the interface, so as to improve the shear strength of the interface [8-9]. This paper intends to analysis the influence of different roughness of surface to the shear strength of interface between PVA-ECC and existing concrete, and obtain the shear performance parameters, which can provide basis for practical projects.

2. The experiment

2.1. Material

The specimens used ordinary Portland cement, ordinary river sand, tap water and gravel with particle size of 5~20mm. The uniaxial compression strength of 28-day concrete is 35.1MPa, and the mix ratio is shown in Table 1.

| Table 1. 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. Specimens

The PVA-ECC specimen preparation and maintenance: PVA-ECC using in situ conservation, to 1.5 m/s speed mixer and stir 60s, makes the aggregate fully mixing, and then add in the 30s, continue to cement mixing experiment closed to prevent dust into the and raw material loss, then add water and water reducing agent and stir 60s, at this time under the condition of not cutting mixer power, stir and add PVA fiber, for all materials to join after mixing, stirring 120s. 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.

Z-type structural specimens were used to carry out the shear performance test of the bond surface. The specific form and size of the specimen are shown in Figure 1.

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

In addition, the surface treatment types of old concrete are divided into four categories, and the roughness assessment principle schematic diagram of the surface of old concrete using average sand pouring method is shown in Figure 2. The specific process of evaluation is: first, 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. The roughness of the treatment surface was represented by the average sand pouring depth (Figure 2). The average sand pouring depth of the treatment surface was calculated by formula (1) and calculated by the average value, which is called average sand pouring method. Statistics after processing are shown in Table2.

![Diagram of average sand irrigation method](image)

Figure 2. Diagram of average sand irrigation method

Averages and depth \( h \) (mm) =

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

(3) Casting Z-type bonding specimen: Soak the old concrete block about 12 hours, after take out put in dry and ventilated place, make its surface moist but not clear water, again will die after brushing oil in a vibration table, the old concrete block in the corresponding position, finally will PVA-ECC and used to populate the new concrete respectively poured into the mold. The specimen vibration molding after 20–30 s. After 36–48 hours of molding, the specimen was removed and placed in the room. After watering, the specimen was covered with plastic cloth for curing (temperature 20±2°C, relative humidity above 95%) until the age of 28 days.

### Table 2. Statistical results of the four treatment surfaces

| Type | Measurement                                      | surface feature     | Sample number | Mean sand depth (mm) |
|------|--------------------------------------------------|---------------------|---------------|----------------------|
| I    | Brush off only the floating ash                  | Almost smooth       | 11            | 0                    |
| II   | Surface chiseling, remove loose mortar           | A little uneven     | 18            | 1.43                 |
| III  | Chisel the coarse aggregate and mortar off the surface | Distinct unevenness | 18            | 2.61                 |
| IV   | Treated with groove method                       | Trench with 20mm wide and 10mm depth | 6             | 4                    |

### 2.3. Test setup

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, glue the fixture with 502 to the corresponding positions on both sides of the middle height of the bonding surface, and fix the digital indicator to measure the relative displacement of the two parts. Then, the testing machine was started to continuously and uniformly load at the speed of 0.5kN/min until the specimen was destroyed, and the load and displacement data were collected respectively.
3. Test results and analysis

3.1. Test phenomena and failure characteristics

The damage form of four kinds of interface treatment respectively: the failure surface of I type specimen is relatively smooth, the water in the old concrete surface is only a small amount of PVA-ECC slurry, and the bond is weak which mainly comes from the cementing force and friction force between PVA-ECC and concrete. When II type specimen damage, Aggregate projecting from old concrete have thicker cement mortar of PVA-ECC, instructions in these places have hardened cement mortar has been cut, but there is no aggregate is cut off; In addition to the bonding force and friction force, there is also mechanical bite force, so the bonding force is slightly higher. When type III specimen damage, In addition to the hardened cement mortar was cut, the old concrete surface can also be seen a few aggregate was cut, 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. type IV specimen due to cut a groove, groove is completely PVA-ECC fill, destroy the groove when the PVA-ECC was cut along the bonding surface, fracture surface is flat; At this time, the binding action is basically provided by the shear action of PVA-ECC, so the binding force is obviously improved.

3.2. Test results and analysis of shear performance

The adhesive strength can be calculated according to the average shear stress on the shear surface, and the formula is shown in Formula (2).

\[ \tau = \frac{V}{A} \] (2)

Where, \( V \)-shear failure load (N); \( A \)-Interface area (mm²).

Considering the adhesive specimens bonded surface early strength is low, when dismantle might affect their later development of strength, so that the test results of large discreteness, this test for type I–III interface made six each group a total of 18 specimens; In the process of mold removal, many I specimens were damaged, and only 11 specimens remained. Type IV specimen due to the slot of PVA-ECC embedded in it, the bonding surface performance is more stable, so the production of two groups, a total of 6 specimens; the whole concrete specimen is also made of 2 groups of 6.

In this paper, the shear strength test results of all types of specimens and concrete specimens as a whole are statistically analyzed, and the relevant parameters obtained are shown in Table 3. Note that the mean depth \( h \) of pouring sand is the average of all samples 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                |
According to the test results obtained in Table 3, the mean shear strength of all types of interfaces was compared, as shown in Figure 3. The mean shear strength of type II interface increased by 43.9% than type I, and that of type III interface increased by 66.7% than of type II, as well as a 140% increase over type I.

As can be seen from the Table3 that the mean shear strength of type IV interface are improved obviously, which is 102.7% higher than that of type III interface. As mentioned above, type IV specimens were cut grooves on the surface of the interface, where grooves were filled by PVA–ECC. The contribution of the bonding shear force is mainly provide by PVA-ECC, which can be thought material shear stress. This is slightly different from the type I–III interface. Therefore, the shear strength of type IV interface has improved significantly.

In addition, it can be calculated by the data in Table 3 that 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. And also, based on the test data, the curve between interface roughness and interface shear strength is obtained as shown in Figure 4. According to the test data regression analysis, the regression curve of interface shear strength is also shown in Figure 4, where the regression equation is expressed in Formula (3).

$$\tau = 1.10092h - 0.50994$$  \hspace{1cm} (3)

Where, $\tau$ - shear strength (MPa), $h$ - Average depth (mm).

For the Formula (3), the linear fitting correlation coefficient is $R=0.79377$, and the critical value is 0.403 when $\alpha=0.01$ based on the test of significance for coefficient of correlation, which indicates that the regression equation is significant.
3.3. Shear stress-slip curve of interface

Based on the data processing, the shear stress-slip curve of the interfaces with different roughness is obtained, as shown in Figure 5. It is clear that slip value of type I interface is minimal, and especially after the peak stress, the interface stress drops rapidly, damage occurred with no obvious horizontal slide. Slippage of type II and III specimen are larger, and the interface stress slow decline at the peak stress while there is deformation slip in long horizontal. Due to the PVA-ECC in the groove bearing shear force, the shear performance of type IV interface is improved observably, as well as shear slip also increased significantly. It can be seen that with the increase of roughness, the peak slip increases, and also the horizontal extension section under the failure shear stress becomes longer, which indicates that the roughness of the interface improves the ductility of the interface. When the old concrete structure is strengthened, it can be considered to cut grooves in the interface due to its high shear capacity.

![Figure 5. Shear stress-slip curve of interface](image)

It can also be seen from Figure 5 that z-type specimens with treatment of interface generally have the following four stages in the development process of shear stress-slip curve of the interface. The first one is elastic deformation stage. This is the initial stage of deformation. The curve is an upward sloping segment, indicating that the interface is in the state of elastic deformation. The shear stress increases rapidly, but the total deformation is very small. At this point, the interface bears a certain shear stress, and the shear deformation increases after overcoming the static friction force. The second one is nonlinear stage. This stage is the transition zone from the elastic deformation stage to the plastic slip stage. The third one is plastic slip stage. At this point, the uneven aggregate on the interface is successively cut, resulting in a rapid increase in slip amount and significant deformation. When it reaches the peak stress, the bonding slip continues increasing while the shear stress is almost unchanged. The last one is destruction stage. In the stage, all sections of the interface bearing shear force are basically destroyed. The shear stress almost drops along a straight line, and the specimen is suddenly destroyed by shear force. It can be seen in Figure 6 that the descending part of the curve of type IV specimen falls slowly after the peak stress, which indicates that PVA-ECC still has certain shear capacity.

4. Conclusion

(1) According to the specimen test results, it is clear that 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, the interface is rougher, the bonding effect is more obvious.

(2) The Z-type interface between PVA-ECC and old concrete is reasonable, which can make shear stress uniform distribution in the interface and avoid large bending stress and stress concentration.

(3) According to the shear stress-slip curve of the interface under different roughness, it is clear that the peak slip amount and shear strength also increase with the increase of roughness, and the horizontal...
extension section under the failure shear stress also becomes longer, which indicates that the rougher the interface, the better the ductility of the interface.

(4) An approximate linear relationship between shear strength and interface roughness is obtained by regression analysis as well as the regression equation, which can be used in the practical engineering.

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