Bond Properties between Continuous Fiber Rope and Concrete

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ABSTRACT

Continuous Fiber Rope is made of Aramid fiber or Vinylon fiber and shaped in the form of rope as reinforcement for concrete members. It is characterized by a lightweight, a high tensile strength and an excellent durability compared with reinforcing steel bar. It has also a good transportability, and it is flexible to be easily arranged at a construction site. The authors have already investigated not only the tensile properties of Continuous Fiber Rope but also the capacities of some kinds of splice of Continuous Fiber Rope. In this research, in order to investigate the bond properties between Continuous Fiber Rope and concrete the pull-out tests of Continuous Fiber Rope with small diameter and large diameter were carried out. The bond strength of Continuous Fiber Rope was much lower than that of a deformed steel bar. Moreover, the slippage of the free end of Continuous Fiber Rope was much larger than that of a deformed steel bar.

KEYWORD

Continuous Fiber Rope, Aramid fiber, Vinylon fiber, bond property, pull-out test
1. INTRODUCTION

Continuous Fiber Rope (CF Rope) is made of Aramid fiber or Vinylon fiber and shaped in the form of rope as reinforcement for concrete members. It is characterized by a lightweight, a high tensile strength and an excellent durability compared with reinforcing steel bar. It has also a good transportability, and it is flexible to be easily arranged at a construction site.

The authors have already investigated not only the tensile properties of CF Rope but also the capacities of some kinds of splice of CF Rope [1, 2]. In this research, in order to investigate the bond properties between CF Rope and concrete the pull-out tests of CF Rope with small diameter and large diameter were carried out. The bond strength of CF Rope was much lower than that of a deformed steel bar. Moreover, the slippage of the free end of CF Rope was much larger than that of a deformed steel bar.

2. APPLICATION OF CF ROPE

When CF Rope is used as the shear reinforcement of a newly constructed concrete member, it is arranged around the longitudinal steel reinforcements as shown in Fig.1.

When CF Rope is used for seismic retrofitting of an existing concrete member, it is wound around the surface of the concrete member as shown in Fig.2. The seismic retrofitting method using CF Rope with concrete jacketing was developed by Phong, etc [3].

3. BACKGROUND OF CF ROPE

Continuous Fiber Reinforcement (CF Reinforcement) is made of fiber impregnated with resin and shaped in the form such as rod or grid. It is used as the substitution of a steel bar or a prestressing tendon. The researches on CF Reinforcement were started in the beginning of 1980s, when the durability of concrete structures that were damaged by salt attack was discussed. Owing to the collaboration of the government, the universities and the companies, CF Reinforcement has been first put to practical use in Japan leading other countries.

Continuous Fiber Sheet (CF Sheet) is bonded with resin to the surface of an existing concrete member to retrofit it. Since CF Sheet has a high retrofitting effect without an increment of weight, it is applied to seismic retrofitting of a pier and a chimney, retrofitting of a tunnel and other concrete structures, or preventing from exfoliation of concrete.

CF Reinforcement or CF Sheet should be impregnated with resin in the factory or at the construction site. In order to improve this time-consuming work CF Rope has been newly developed. Concerning CF Reinforcement and CF Sheet, the recommendation for design and construction for concrete structures using each continuous fiber material has been published by the Japan Society of Civil Engineers (JSCE). Moreover, the evaluating method for these materials has been established [4, 5]. However, the evaluating method for CF Rope has not been established yet.
4. MATERIALS

4.1 Continuous Fiber Rope

(1) CF Rope with small diameter

The types of CF Rope with small diameter used in this study were Aramid fiber rope (T), Vinylon fiber rope (K) and Vinylon fiber rope (Y). These three types of CF Rope were stranded by each fiber as shown in Fig.3. Then, only the surface of CF Rope was coated with urethane resin. Through coating with urethane resin, the fibers were prevented from being unbraided, moreover CF Rope became a little harder and easy for handling.

Table 1 shows the properties of three types of CF Rope with small diameter. The values shown in Table 1 do not include urethane resin.

<table>
<thead>
<tr>
<th>Type of rope</th>
<th>Nominal diameter (mm)</th>
<th>Sectional area (mm²)</th>
<th>Tensile strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aramid fiber (T)</td>
<td>6.0</td>
<td>11.5</td>
<td>2414</td>
</tr>
<tr>
<td>Vinylon fiber (K)</td>
<td>6.0</td>
<td>12.5</td>
<td>556</td>
</tr>
<tr>
<td>Vinylon fiber (Y)</td>
<td>6.0</td>
<td>12.3</td>
<td>851</td>
</tr>
</tbody>
</table>

(2) CF Rope with large diameter

The types of CF Rope with large diameter used in this study were Aramid fiber rope (T) and Vinylon fiber rope (Y). These two types of CF Rope were stranded by each fiber as shown in Fig.4. Only the surface of Aramid fiber rope (T) was coated with urethane resin. However, the surface of Vinylon fiber rope (Y) was not coated. If Vinylon fiber rope (Y) with a large diameter is coated with urethane resin, it will become harder and difficult for handling. This point is different from the case of Vinylon fiber rope (Y) with small diameter.

Table 2 shows the properties of two types of CF Rope with large diameter. The values shown in Table 2 do not include urethane resin, either.

<table>
<thead>
<tr>
<th>Type of rope</th>
<th>Nominal diameter (mm)</th>
<th>Sectional area (mm²)</th>
<th>Tensile strength (N/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aramid fiber (T)</td>
<td>15.0</td>
<td>57.7</td>
<td>1340</td>
</tr>
<tr>
<td>Vinylon fiber (Y)</td>
<td>15.0</td>
<td>61.7</td>
<td>468</td>
</tr>
</tbody>
</table>

4.2 Concrete

In order to decrease the change of strength of concrete due to the age of concrete at the pull-out tests, high early strength portland cement was used. The maximum size of coarse aggregate was 20 mm. The slump of concrete was 12.1 cm after mixing. The water-cement ratio was 55%.

The compressive strength of concrete at the pull-out tests of CF Rope with large diameter (at 7 days) and that at the pull-out tests of CF Rope with small diameter (at 14 days) were 33.9 N/mm² and 38.6 N/mm², respectively.

5. SPECIMEN

5.1 Specimen for CF Rope with Small Diameter

Figure 5 shows the dimension of specimen for the pull-out tests for CF Rope with small diameter. The whole length of CF Rope was 1725 mm, and 260 mm of the right end was impregnated with epoxy resin with low viscosity. Usually this epoxy
resin has been used to be injected into a crack of concrete.

After hardening of epoxy resin, the steel pipe 250 mm long, 27.2 mm of the outer diameter and 5.5 mm thick was inserted. Then, a highly expansive paste was poured into the steel pipe according to “Test Method for Tensile Properties of Continuous Fiber Reinforcing Materials Using Highly Expansive Paste” in “Recommendation for Design and Construction for Concrete Structures Using Continuous Fiber Reinforcing Materials” proposed by JSCE [4]. When the pressure of the highly expansive paste was applied to CF Rope without epoxy resin, it might be absorbed by CF Rope and disappear. Therefore, the part of CF Rope that was inserted into the steel pipe was impregnated with epoxy resin, and it became CF Reinforcement.

Concrete block was a cubic with 100 mm length of one face. In the center of the form CF Rope was arranged horizontally, then it was fabricated by placing concrete around CF Rope.

“Test Method for Bond Strength of Continuous Fiber Reinforcing Materials by Pull-out Testing” in “Recommendation for Design and Construction for Concrete Structures Using Continuous Fiber Reinforcing Materials” describes that the bond length of CF Reinforcement shall be set up in the free end, and it shall normally be four times the apparent diameter of CF Reinforcement [4]. However, the nominal diameter of CF Rope with small diameter used in this test was only 6.0 mm, when the bond length was 24 mm that was four times the nominal diameter, it was too short and it would lead to an error in fabricating a specimen. Therefore, the bond length was 36 mm that was six times the nominal diameter.

In order to equalize the stress from the loading plate on the loaded end side, the surface other than the bond surface of CF Rope shall be sheathed to prevent from bonding to concrete with a vinyl chloride pipe. Three specimens were manufactured for each type of CF Rope, and the total number of the specimens was nine.

5.2 Specimen for CF Rope with Large Diameter

Figure 6 shows the dimension of specimen for the pull-out tests for CF Rope with large diameter. The whole length of CF Rope was 1775 mm, and 370 mm of the right end was impregnated with epoxy resin with low viscosity.

After hardening of epoxy resin, the steel pipe 350 mm long, 42.7 mm of the outer diameter and 6.4 mm thick was inserted as shown in Fig. 7. Then, a highly expansive paste was poured into the steel pipe.

![Fig.6 Dimension of specimen (large diameter)](image)

![Fig.7 CF Rope and steel pipe](image)

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![Fig.6 Dimension of specimen (large diameter)](image)

![Fig.7 CF Rope and steel pipe](image)
Concrete block was a cubic with 150 mm length of one face. In the center of the form CF Rope was arranged horizontally, then it was fabricated by placing concrete around CF Rope as shown in Fig.8. The bond length was 90 mm that was six times the nominal diameter of CF Rope (15.0 mm) as same as that with small diameter. Three specimens were manufactured for each type of CF Rope, and the total number of the specimens was six.

6. TEST METHOD

The test method for the specimen with CF Rope with large diameter was the same as that with CF Rope with small diameter. Therefore, from now on, the former should be described.

The capacity of the testing machine for the pull-out tests was 2000 kN.

The steel loading plate was a square with 300 mm length of one side, and the rubber plate was a square with 150 mm length of one side. Both plates had a hole through which the steel pipe should pass. The loading plate and the rubber plate were placed on the upper frame of the testing machine, and then, the concrete block was mounted on the rubber plate.

In order to measure the slippage of the free end of CF Rope, the surface of CF Rope over the upper surface of the concrete block was marked at the interval of 5 mm with an oil marker as shown in Fig.9.

The steel pipe at the lower end of the specimen was directly gripped by the testing machine, and then, a pull-out force was applied to CF Rope as shown in Fig.10 according to “Test Method for Bond Strength of Continuous Fiber Reinforcing Materials by Pull-out Testing”[4]. The slippage of the free end of CF Rope was measured at the interval of 5 mm with the eye, and the corresponding load was recorded. The precision of the slippage of the free end was not so sufficient.

7. TEST RESULTS

7.1 Bond Strength

The bond strength was calculated according to Eq. (1)

\[ \tau_u = \frac{P_u}{U\ell} \]  

where,

- \( \tau_u \) : bond strength (N/mm\(^2\))
- \( P_u \) : maximum load (N)
- \( U \) : nominal peripheral length of CF Rope (mm)
  
  \[ U = \pi D \]
- \( D \) : nominal diameter (mm)
- \( \ell \) : bond length (mm)

The bond strength of CF Rope with small diameter and that of CF Rope with large diameter are shown in Fig.11 and Fig.12, respectively. Since the capacity of the testing machine was high, the precision of the bond strength of CF Rope with small diameter was not so sufficient.

The averages of the bond strength of Aramid fiber rope (T), Vinylon fiber rope (K) and Vinylon fiber rope (Y) with small diameter were 0.166 N/mm\(^2\), 0.092 N/mm\(^2\) and 0.201 N/mm\(^2\), respectively. The scatter of the bond strength was large, especially that of the bond strength of Aramid fiber rope (T)
was very large. Since the bond strength of No.3 and No.6 was extremely low due to insufficient compaction during placement of concrete, these values were eliminated in calculation of the averages.

The averages of the bond strength of Aramid fiber rope (T) and Vinylon fiber rope (Y) with large diameter were 0.523 N/mm² and 0.521 N/mm², respectively. The scatter of the bond strength was large as same as CF Rope with small diameter, especially that of the bond strength of Vinylon fiber rope (Y) was very large. The bond strength of No.15 was extremely low and it was eliminated in calculation of the average due to the same reason.

The bond strength of CF Rope with large diameter was higher than that of CF Rope with small diameter. In case of Aramid fiber rope (T) the former was approximately 3.1 times higher than the latter, and in case of Vinylon fiber rope (Y) the former was approximately 2.6 times higher than the latter. Since an unevenness of the surface shape of CF Rope with large diameter became more remarkable than that of CF Rope with small diameter, the bond strength of the former became higher than that of the latter.

7.2 Relationship between Bond Stress and Slippage of Free End
The relationship between the bond stress and the slippage of the free end of each specimen was shown in Fig.13 to Fig.17, respectively.

Concerning CF Rope with small diameter only a rough behavior could be clarified due to a large measurement interval of slippage (5 mm). In case of Aramid fiber rope (T) and Vinylon fiber rope (Y) the bond stress became maximum when the slippage was between 10 to 20 mm. In case of

![Fig.11 Bond strength (small diameter)](image1)

![Fig.12 Bond strength (large diameter)](image2)

![Fig.13 Bond stress–slippage relationship](image3)

![Fig.14 Bond stress–slippage relationship](image4)
Vinylon fiber rope (K) the bond stress became maximum when the slippage of the free end was between 5 to 15 mm. Consequently, the slippage at the maximum bond stress became small when the tensile rigidity of CF Rope was low.

Concerning CF Rope with large diameter a detailed behavior could be clarified. In case of Aramid fiber rope (T) the bond stress became maximum when the slippage of the free end was between 40 to 45 mm. In case of Vinylon fiber rope (Y) the bond stress became maximum when the slippage of the free end was between 25 to 35 mm. The reason was that the tensile rigidity of Vinylon fiber rope (Y) was lower than that of Aramid fiber rope (T).

8. COMPARISON WITH BOND PROPERTY OF DEFORMED STEEL BAR

Figure 18 shows the relationship between the bond stress and the slippage of the free end of a deformed steel bar shown in “Test Method for Bond Strength of Continuous Fiber Reinforcing Materials by Pull-out Testing”[4]. Neither the diameter of the deformed steel bar nor the strength of concrete was known.

The bond strength of CF Rope was much lower than that of the deformed steel bar. Moreover, the slippage of CF Rope was much larger than that of the deformed steel bar.

In case of CF Rope with large diameter the slope of the relationship between the bond stress and the slippage did not change much until the bond stress became maximum. However, in case of the deformed steel bar the slope of the relationship between the bond stress and the slippage changed remarkably at the initial stage.
9. CONCLUSIONS

(1) The averages of the bond strength of Aramid fiber rope (T), Vinylon fiber rope (K) and Vinylon fiber rope (Y) with small diameter were 0.166 N/mm$^2$, 0.092 N/mm$^2$ and 0.201 N/mm$^2$, respectively. The scatter of the bond strength was large.

(2) The averages of the bond strength of Aramid fiber rope (T) and Vinylon fiber rope (Y) with large diameter were 0.523 N/mm$^2$ and 0.521 N/mm$^2$, respectively. Since an unevenness of the surface shape of CF Rope with large diameter became more remarkable, the bond strength became higher.

(3) The bond stress of CF Rope with small diameter and that of CF Rope with large diameter became maximum when the slippage of the free end were between 5 to 20 mm and between 25 to 45 mm, respectively. The slippage at the maximum bond stress became small when the tensile rigidity of CF Rope was low.

(4) The bond strength of CF Rope was much lower than that of a deformed steel bar. Moreover, the slippage of the free end of CF Rope was much larger than that of a deformed steel bar.

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REFERENCES


