A Fundamental Study on the Anchor Performance of Non-Surface Treated Multi CFRP Tendons

Woo-tai Jung, Jong-sup Park, Jae-yoon Kang, Moon-seoung Keum

***Abstract*—**CFRP (Carbon Fiber Reinforced Polymer) is mainly used as reinforcing material for degraded structures owing to its advantages including its non-corrodibility, high strength and lightweight properties. Recently, dedicated studies focused not only on its simple bonding but also on its tensioning. The tension necessary for prestressing requires the anchoring of multi-CFRP tendons with high capacity and the surface treatment of the CFRP tendons may also constitute an important issue according to the type of anchor. The wedge type, swage type or bonded type anchor can be used to anchor the CFRP tendon. The bonded type anchor presents the disadvantage to lengthen the length of the anchor due to the low bond strength of the CFRP tendon without surface treatment. This study intends to overcome this drawback through the application of a method enlarging the bond area at the end of the CFRP tendon. This method enlarges the bond area by splitting the end of the CFRP tendon along its length and can be applied when CFRP is produced by pultrusion. The application of this method shows that the mono-CFRP tendon and 3-multi CFRP tendon secured the anchor performance corresponding to the tensile performance of the CFRP tendon and that the 7-multi tendon secured anchor performance corresponding to 90% of the tensile strength due to the occurrence of buckling in the steel tube anchorage.

***Keywords*—**Carbon fiber reinforced polymer (CFRP), Tendon, Anchor, Tensile property, Bond strength.

I. Introduction

OWING to its advantages like non-corrodibility, high strength and lightweight properties, CFRP (Carbon Fiber Reinforced Polymer) is today the subject of researches intending to exploit it as material replacing steel reinforcement and steel wires. CFRP is currently mainly used as reinforcing material to strengthen deteriorated bridges or other structures in various forms including CFRP plates and sheets. In general, the strengthening of the structure is performed by driving a groove in the surface to be reinforced by the CFRP reinforcements and by embedding the member near the surface (NSM, Near Surface Mounted) or by bonding the member on the surface. However, such strengthening method cannot improve the cracks or the deflection. Additional jacking force should be introduced inside or outside the structure to enhance its serviceability by improving the cracks or the deflection. Therefore, the improvement of the serviceability of the structure through the use of CFRP reinforcements as tendon necessitates an anchorage method enabling to anchor the CFRP tendon up to its tensile strength.

Woo-tai Jung is with the Structural Engineering Research Division, Korea Institute of Construction Technology, Republic of Korea (phone: 82-31-9100-580; fax: 82-31-9100-121; e-mail: woody@kict.re.kr).

Jong-sup Park is with the Structural Engineering Research Division, Korea Institute of Construction Technology, Republic of Korea (e-mail: jSpark1@kict.re.kr).

Jae-yoon Kang is with the Structural Engineering Research Division, Korea Institute of Construction Technology, Republic of Korea (e-mail: jykang@kict.re.kr).

Moon-seoung Keum is with the Structural Engineering Research Division, Korea Institute of Construction Technology, Republic of Korea (e-mail: moonseoung@kict.re.kr).

Since CFRP is generally vulnerable to lateral shear, a special anchorage is required to measure the anchor performance of CFRP. Currently, various specifications like ASTM, ACI and CSA and anchorages are proposed for the measurement of the tensile performance of FRP. The anchorages suggested in these specifications can be roughly classified into bonded type and grip type anchorages. Here, the grip type is adapted to low strength FRP because of the stress concentration in the grip like the wedge type anchorage and presents the problem of requiring a grip fitted to the diameter of the tendon. Despite of the need for sufficient anchor length, the bonded type is adapted to high strength FRP and is used in most of the tensile performance tests.

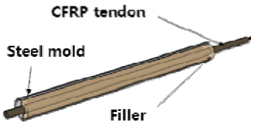
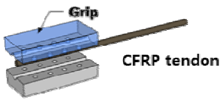
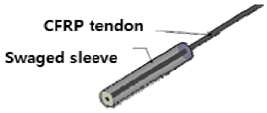
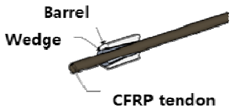
The length of the bonded type anchor varies according to the bond strength of FRP and filling material. The bond strength is itself subordinated to the surface treatment method of CFRP, the surface roughness and the fabrication method. In case of high strength CFRP or when the surface treatment strength is low or inexistent, securing the tensile performance of the material becomes difficult if the length of the bonded type anchor is insufficient.

This study intends to investigate the anchor performance of multi-CFRP tendons without surface treatment. To that goal, an anchoring method improving the bond performance of the non-surface treated CFRP tendon is proposed and anchor performance test is conducted on mono, 3-strans and 7-strans CFRP tendons.

II. Improvement of Anchoring Method

The application of the conventional wedge type anchorage for PS steel wire is difficult in the case of CFRP tendon. Even of the fabrication of the swage type anchorage is easy, the adequate pressure should derived to induce the rupture strength of the CFRP tendon and necessitates further studies. Besides, the bonded type is usually applied for testing FRP [1]-[3]. However, the bonded type presents the problem of requiring long anchor length in case of low surface bond strength.

TABLE I
COMPARISON OF THE ANCHOR METHODS OF FRP

Method	Bonded type (CSA, ACI, ASTM)	Grip type (ASTM)	Swage type	Wedge type
				
Features	• Need of sufficient anchor length • Low cost manufacture possible • Outstanding adaptation to the variation in the diameter of the tendon	• Stress concentration in the grip • Need for grip per diameter	• Possibility to shorten the anchor length • High cost manufacture – Need of special equipment	• Minimal anchor length • Stress concentration in wedge

Even if the anchorage is necessary to evaluate the fundamental properties of CFRP, it is also important not only when anchoring single but also multi-tendons. Especially, since the application of the listed anchor methods presents difficulties for the anchoring of the high capacity CFRP tendon, need is for further improvements.

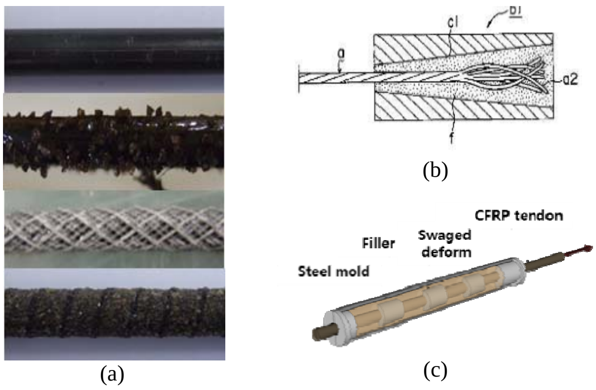


Fig. 1 Methods for the improvement of bond characteristics

An improvement for the anchoring of the CFRP tendon can be achieved by improving the bond characteristics. This can be realized by (a) increasing the bond strength through the change of the surface shape of the CFRP tendon and (b) enlarging the bond area through the splitting of the end of the tendon like in steel wire.

In order to anchor the tendon by a short anchor length, the end of the PS steel wire (12.7mm) can be split into 7 strands as shown in Fig. 1 (b) [4]. In such case, the bond area enlarges by about 2.3 times compared to the original shape before splitting the extremity. Even if the PS steel wire can be split into strands, the fibers of the CFRP tendon are tied by resin making it impossible to split the tendon into strands.

The splitting of the extremity of the CFRP tendon necessitates to remove the resin. In general, this can be achieved by chemical dissolution and thermal dissolution. However, the fabrication process requires a long period since the tendon must be reshaped by reusing the resin after its removal by these methods. Furthermore, the portion at which the reshaped cross-section starts is likely to experience failure due to the damage of the fibers and the concentration of stress.

Apart from the chemical dissolution and thermal dissolution, there is also the method dividing the resin in the direction of the fibers to enlarge the bond area by splitting the end of the CFRP tendon. In general, the fibers of CFRP reinforcements, tendon and cable are produced unidirectionally and the resin fulfills the role of binding the fibers. Accordingly, if the resin is divided into regular portions at the end of the CFRP tendon as shown in Fig. 2, the resin can be easily split in the direction of the fibers [5]. Even if this latter method results in slightly smaller bond area than that obtained by removing completely the resin, it is highly workable and does not need to reshape the end of the tendon by applying new resin. This study intends to apply such method to improve the anchor performance of the CFRP tendon exhibiting poor bond characteristics.

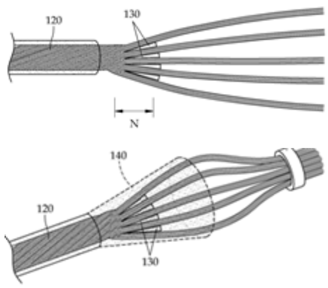


Fig. 2 Improvement of bond characteristics

III. ANCHOR PERFORMANCE TEST OF MONO CFRP TENDON

A. Fabrication of Specimen and Test Method

The features of the CFRP tendon without surface treatment used in this study are listed in Table II.

TABLE II
BASIC CHARACTERISTICS OF CFRP TENDON

CFRP tendon	Diameter (mm)	Cross sectional area (mm^2)	Tensile strength (MPa)	Elastic modulus (GPa)
Mono and 3-multi	5	19.63	3500	190
7-multi			4000	230
Shape				

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:7, No:11, 2013

TABLE III
ANCHOR PERFORMANCE TESTS RESULTS OF MONO-CFRP TENDON

Specimen	Maximum load (kN)	Stress (MPa)	Maximum displacement (mm)	Strain ($\times 10^{-6}$)	Elastic modulus (GPa)
1	69.71	3550	17.11	18763	190
2	69.92	3561	16.50	19047	202
3	65.82	3352	14.50	17237	186
4	73.36	3736	17.21	19782	195
5	68.93	3510	-	-	179
Mean	69.55	3541			190

The cross-section of the CFRP tendon end is quadrisected so as to enlarge the bond area by dividing the resin in the direction of the fibers as shown in Fig. 3. The so-obtained end is also additionally treated by alumina oxide coating to improve the bond force and fiber reinforcement is applied to increase the lateral confinement of the split end. The specimen of which the bond area of the extremity has been enlarged was then inserted in a bonded type anchorage manufactured using a steel tube anchor with diameter of 42.7mm and length of 400mm similarly to the usual bond test. Identically to the basic properties test, loading was applied using a UTM with capacity of 980 kN through displacement control at speed of 0.0835 mm/sec. A 5mm gage was disposed at the center of the specimen to measure the strain.

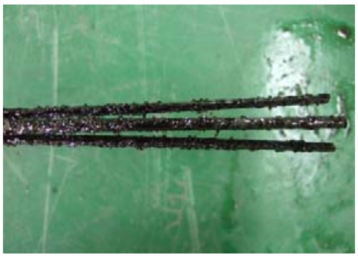


Fig. 3 Oxide coating

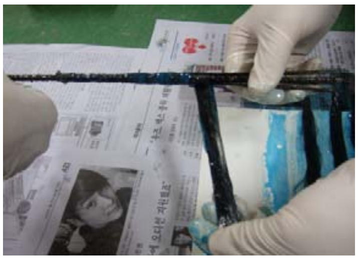


Fig. 4 Fiber reinforcement

B. Tensile Test Results

The tensile test was conducted in compliance with the standard test method on 5 manufactured specimens. The test results are arranged in Table III.

As shown in Fig. 5, the failure modes occurred through the progressive rupture of the CFRP fibers. The measurement revealed a tensile strength, an elastic modulus and a failure strain larger than 3500 MPa, 190 GPa and 1.8%, respectively. Since the anchoring of a CFRP tendon without surface treatment or with low bond strength requires long anchor length, it is inefficient. However, the results of the test applying the method enlarging the bond area on the tendon end showed that the anchor performance reached the tensile strength of the CFRP tendon. Accordingly, this method is applied to test the anchor performance of the multi-CFRP tendons with 3 strands and 7 strands.

Fig. 5 View of tensile test and failure pattern

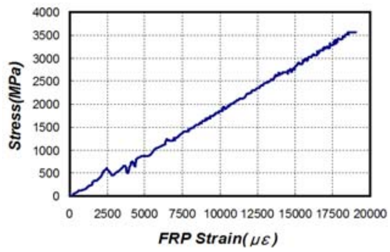


Fig. 6 Load-displacement curve

IV. ANCHOR PERFORMANCE TEST OF 3-STRAND AND 7-STRAND MULTI-CFRP TENDONS

A. Fabrication of Specimen

In order to fabricate the specimens for the anchorage of the 3 and 7-multi CFRP tendons, the end of the mono CFRP tendon was first quadrisected identically to the previous method and 3 or 7 CFRP tendons were gathered and subjected to oxide coating over their embedded length. The tensile strength of the CFRP tendon used in the 3-multi is 3500 MPa as the mono CFRP tendon and 4000 MPa for that used in the 7-multi. The completed multi-tendons anchorage was tested using the same method used for the anchor test of the mono CFRP tendon.

Fig. 7 3-multi CFRP tendon

Fig. 8 7-multi CFRP tendon

B. Test Results of 3-Multi CFRP Tendon

Table IV arranges the test results. Figs. 9 and 10 present the failure pattern of the CFRP tendon and its load-displacement curve, respectively. In view of the multi-anchor test results, the failure mode occurred through rupture at the center of the CFRP tendon similarly to the failure pattern of the single tendon (Fig. 5). Since the material performance of the CFRP tendon is similar to that of the mono CFRP tendon, it appears that no loss of the performance occurred.

C. Test Results of 7-Multi CFRP Tendon

The failure mode in the 7-multi anchor test is similar to that observed in the mono and 3-multi tendons. However, the cross sectional area of the anchor steel tube appears to secure insufficient performance to anchor the 7-multi tendon. This resulted in the buckling of the steel tube followed by the rupture of the CFRP tendon. The measurements show that anchor performance reached approximately 90% of the tensile strength of the CFRP tendon.

Fig. 12 plots the load-displacement curve and shows a behavioral change at about 350 kN. This change corresponds to the buckling of the steel tube resulting in the occurrence of slip.

Fig. 9 Failure pattern of 3-multi CFRP tendon

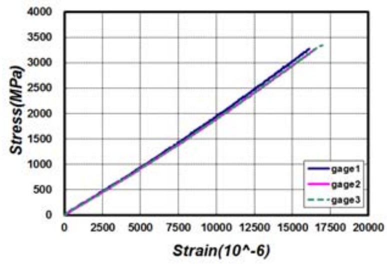


Fig. 10 Load-displacement curve of 3-multi CFRP tendon

Fig. 11 Failure pattern of 7-multi CFRP tendon

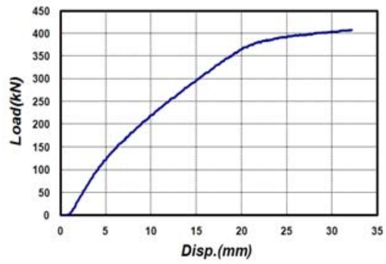


Fig. 12 Load-displacement curve of 7-multi CFRP tendon

TABLE IV
PERFORMANCE TESTS RESULTS OF 3-MULTI ANCHOR

Specimen	Maximum load (kN)	Stress (MPa)	Maximum displacement (mm)	Strain ($\times 10^{-6}$)	Elastic modulus (GPa)
5@3-01	209.71	3560	20.20	-	195
5@3-02	205.11	3482	17.43	17808.53	193
5@3-03	201.7	3242	17.53	17304.26	193

TABLE V
PERFORMANCE TESTS RESULTS OF 7-MULTI ANCHOR

Specimen	Maximum load (kN)	Stress (MPa)	Maximum displacement (mm)	Strain ($\times 10^{-6}$)	Elastic modulus (GPa)
5@7-01	423.28	3145	43.78	13567	233
5@7-02	494	3594	111.78	14568	239

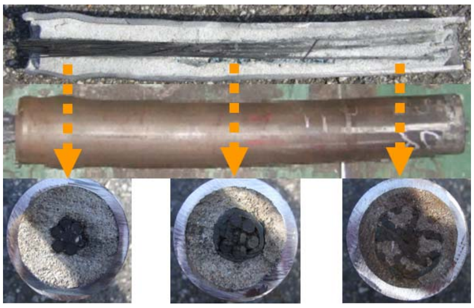


Fig. 13 Cutting of 7-multi CFRP tendon anchorage

Fig. 13 shows the longitudinal and transverse cuts of the buckled steel tube. The observation of the longitudinal cut reveals that the filling mortar is dense in the split tendon at the extremity. In addition, the observation of the transverse cuts shows also the dense filling of the fiber reinforced portion by mortar.

Accordingly, the use of the anchorage considering the tensile performance of the multi-CFRP tendons appears to be adequate for the anchoring of CFRP tendons with more than 7 strands

V. Conclusions

This study carried out tensile tests on a bonded type anchorage in order to evaluate the anchor performance of the multi-CFRP tendons without surface treatment. The following conclusions can be derived from the test results.

1) This study enlarged the bond area of the end of the tendon to improve the bond strength of the CFRP tendon without surface treatment. This method enabled to secure the tensile performance of the CFRP tendon.
2) In view of the test results relative to the mono and 3-multi CFRP tendons, the enlargement of the bond area of the CFRP tendon end was verified to secure anchor performance corresponding to the tensile performance of the CFRP tendon.
3) Even if buckling of the steel tube occurred in the test of the 7-multi CFRP tendon due to the loss of its performance, the anchor performance was seen to reach a level corresponding to 90% of the tensile strength of the CFRP tendon.
4) The method increasing the bond area at the end of the CFRP tendon was verified to secure the anchor performance of the CFRP tendon not only for the mono tendon but also for the multi- tendons. The prevention of the buckling of the anchor in the future will enable to anchor CFRP tendons with more than 7 strands.

Acknowledgment

This research was supported by a grant from a Strategic Research Project funded by the Korea Institute of Construction Technology.

References

[1] Canadian Standard Association (CSA). CSA Standard S806-02 (2002), Design and Construction of Building Components with Fiber-Reinforced Polymers.
[2] ASTM D 3916-08 (2008), Standard Test Method for Tensile Properties of Pultruded Glass-Fiber-Reinforced Plastic Rod.
[3] ACI Committee 440 (2004), Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures, ACI 440.3R-04.
[4] 東京製綱株式會社 (1998), ケーブル端部定着方法及びケーブル端部定着構造, 特開乎10-82178, Japan.
[5] KICT (2010), FRP Cable Anchoring Capability Improving Method and Structure, Patent Application No. 10-2010-0023435, South Korea.

Woo-tai Jung received his MS degree and Ph.D. in Civil Engineering from Myongji University. He is a Senior Researcher at the Structural Engineering Research Division of the Korea Institute of Construction Technology. His research interests are in the area of fiber reinforced concrete & strengthening with FRP reinforcements of deteriorated concrete structures and developing CFRP reinforcements.

Jong-sup Park received his MS degree and Ph.D. in Civil Engineering from Myongji University. He is a Research Fellow at the Structural Engineering Research Division of the Korea Institute of Construction Technology.

Jae-yoon Kang received his MS degree and Ph.D. in Civil Engineering from Dongguk University. He is a Senior Researcher at the Structural Engineering Research Division of the Korea Institute of Construction Technology.

Moon-seoung Keum received his MS degree in Civil and Environmental Engineering from Kookmin University. He is a Post-master Researcher at the Structural Engineering Research Division of the Korea Institute of Construction Technology.