

Experimental Study on Bond Strength of FRP bars

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ABSTRACT: The bond behaviour of reinforced bar is an important issue in the design of reinforced concrete structures. This study focused on the bond strength of steel bar and carbon and Aramid fiber reinforced polymer bars (CFRP, AFRP) in normal strength concrete. To compare bond strengths of selected rebars with various diameters including $\phi 6\text{mm}$, $\phi 8\text{mm}$, and $\phi 10\text{mm}$, pull-out tests were performed with twenty one 200mm cubic specimens with concrete compressive strength of 35 MPa. For each polymer rebar, the test results included the bond stress–slip response and the failure mode.

Keywords: diameter, fiber reinforced polymer, bond strength, pull-out test

1. INTRODUCTION

The steel reinforcement makes up for the concrete which has characteristic of brittle failure as it has equal thermal expansion with concrete. Contact with air and water through concrete crack and neutral response of concrete accelerate corrosion of steel, and this phenomenon causes fatal effects to structural members. So the studies trying to complement defect of steel have been continued. FRP was developed by the results of these researches. This material had excellent advantages on corrosion resistance, high tensile strength, and lightweight. It could be reduced the load by decreasing self-weight of entire structure. FRP bars are made from Aramid fiber (AFRP), glass fiber (GFRP) and carbon fiber (CFRP).

There were various properties which can effect with the bond characteristic. For example, diameter of the rebar, embedment length and rib shape, etc. In this study, the bond strength of CFRP and AFRP was evaluated including various diameters of rebar in normal compressive strength concrete.

2. EXPERIMENTAL PLAN

2.1 Concrete

Concrete mixture proportion was shown in Table I. Compressive strength test of concrete was used to evaluate the concrete performance according to the KS F 2405 standard. The compressive strength of concrete was 34 MPa.

2.2 FRP Reinforced Bars

The FRP bars used in this study were AFRP and CFRP shown in Figure 1 and 2. The AFRP bar was consisted of Aramid fiber and epoxy resin; the CFRP bar was consisted of carbon fiber and epoxy resin. Both types had spiral ribs and sand coating on the surface. In Table II, the mechanical properties were presented. The nominal diameters of rebar were 6, 8 and 10mm.



Figure 1: CFRP rebar



Figure 2: AFRP rebar

2.3 Specimen

The specimens were manufactured according to ACI 440.3R-04 for the pull-out test [1]. The rebars were pulled from 200 mm concrete cube. All the rebars were 760 mm long. The embedded lengths of the reinforced bars were five times of the each bar diameter. PVC tube was used to isolate the debonded section of the concrete.

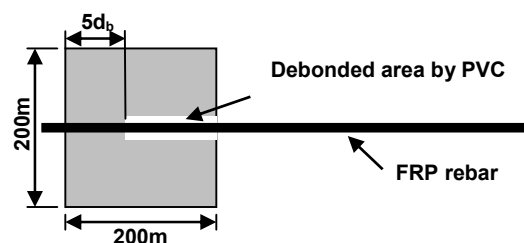


Figure 3: The specimen of the pull-out test

In this study, three identical specimens were manufactured for each FRP type and nominal diameter. And deformed bar was manufactured to compare bond characteristic of rebar.

3. TESTING EQUIPMENT AND SET UP

The Pull-out test to figure out FRP rebar's bond strength was performed according to ACI Standard 440.3R-04. And GRIP to clutch the FRP rebar was manufactured according to ASTM D3916-02 [2]. In Fig 4, the load was applied to the FRP rebar at a rate of 1 mm/min by using universal testing machine (UTM, maximum capacity 1000 kN). All the tests were performed in displace control mode till the FRP rebar was pull out completely. The load was measured with electronic load cell of the machine. A total of three LVDT were used to measure the slips at the loaded end and at the free end.

Table I: Mixture proportion and characteristics of concrete

size of coarse aggregate (mm)	Slump value (mm)	W/C (%)	Gravel (kg/m ³)	Sand (kg/m ³)	Cement (kg/m ³)	Fly Ash (kg/m ³)	Water (kg/m ³)	AD3 (kg/m ³)
25	180	38.8	1029	710	399	44	155	4.87

Table II: Mechanical properties of rebars

Rebar Type	Resin	Density (g/cm ²)	Fiber content (%)	Tensile Strength (MPa)	Elastic Modulus (GPa)
CFRP	epoxy	1.8	75	3900	191
AFRP	epoxy	1.45	65~70	1470	75.6

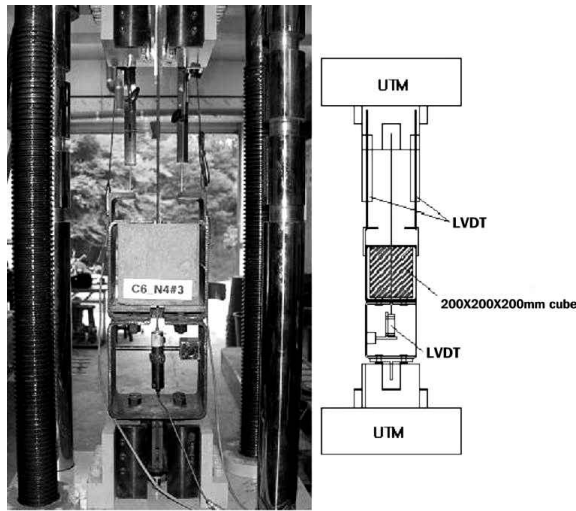


Figure 4: Pull-out test set up

4. RESULT

The results of pull-out test of the FRP rebar were given in Table III.

Table III: Bond test result of specimen

Specimen	Concrete Strength		Ultimate State			Failure Mode
	Compressive	Load	Free end Slip	Load end Slip	Average Bond Stress	
	(Mpa)	(kN)	(mm)	(mm)	(Mpa)	
C6_5 #1	33.99	8.53	2.09	3.29	15.01	Pull-Out
C6_5 #2		10.39	2.13	4.13	18.42	Pull-Out
C6_5 #3		9.60	2.51	4.01	17.04	Pull-Out
C8_5 #1	33.99	18.82	2.35	3.55	18.72	Pull-Out
C8_5 #2		13.43	2.18	4.18	13.34	Pull-Out
C8_5 #3		12.74	2.78	2.96	12.65	Pull-Out
C10_5 #1	33.99	20.97	1.81	3.31	13.33	Pull-Out
C10_5 #2		18.91	2.22	3.91	12.02	Pull-Out
C10_5 #3		17.84	2.47	4.75	11.32	Pull-Out
A6_5 #1	33.99	5.39	0.65	2.05	9.60	Pull-Out
A6_5 #2		3.53	1.76	2.50	6.26	Pull-Out
A6_5 #3		5.88	3.10	4.30	10.35	Pull-Out
A8_5 #1	33.99	9.11	2.31	3.71	9.07	Pull-Out
A8_5 #2		8.82	2.40	4.40	8.80	Pull-Out
A8_5 #3		12.54	2.25	4.17	12.50	Pull-Out
A10_5 #1	33.99	10.98	0.47	1.50	6.98	Pull-Out
A10_5 #2		13.92	2.24	4.24	8.87	Pull-Out
A10_5 #3		14.21	2.25	4.25	9.07	Pull-Out
S10_5 #1	33.99	20.38	4.21	5.79	13.00	Pull-Out
S10_5 #2		30.09	3.61	5.47	19.13	Pull-Out
S10_5 #3		21.17	3.76	5.55	13.44	Pull-Out

The identification code of specimen is named as follows.

CBD_K

Where,

C = the type of the FRP rebar

BD = the diameter of the FRP rebar

K = the multiplier for embedment length.

Average bond stress was calculated by the pull-out load. Hence the failure modes were found out by pull-out test.

4.1 Relationships of Bond Stress-Slip

In this experiment, all of the specimens were failed by pull-out of rebar. Figure 5 and 6 described the relationship of the average bond stress and slip by considered parameter. Pull-out load decreased rapidly after the ultimate load. It was similar to relationship of the average bond stress and slip of the deformed bar in Figure 7.

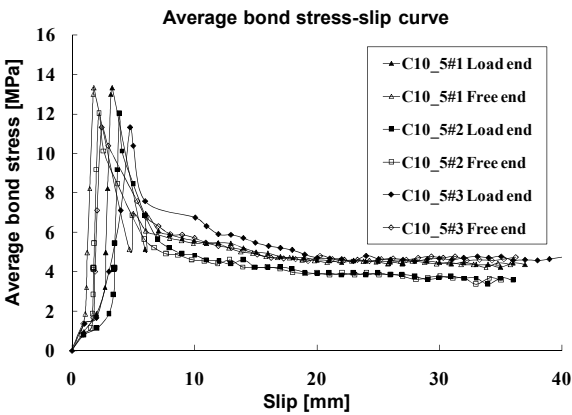


Figure 5: C10_5 Average bond stress-slip curve

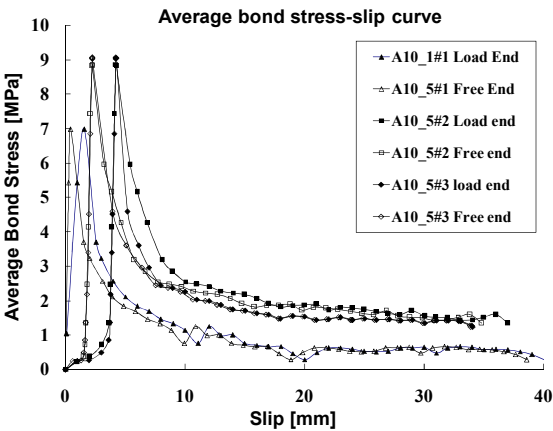


Figure 6: A10_5 Average bond stress-slip curve

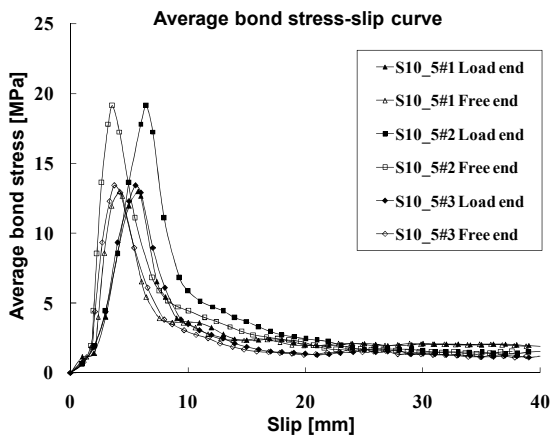
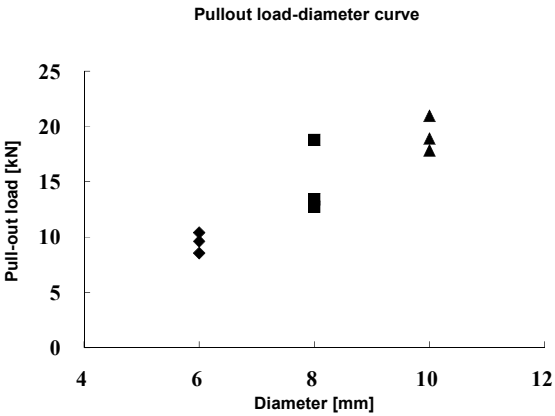


Figure 7: S10_5 Average bond stress-slip curve

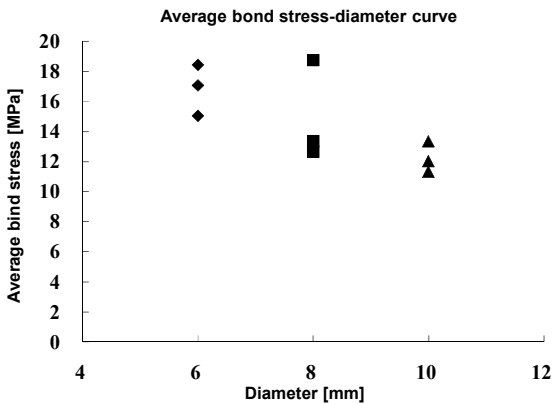
4.2 Relationship with Bond Characteristic and Diameter

Figure 8 and 9 show that the bond characteristics of CFRP rebar and AFRP rebar. As the diameter of rebar increased, the maximum pull-out load increased because of

the friction area. But average bond stress decreased when the diameter of rebar increased because of the contact surface with concrete. It was similar result in the previous paper [3].

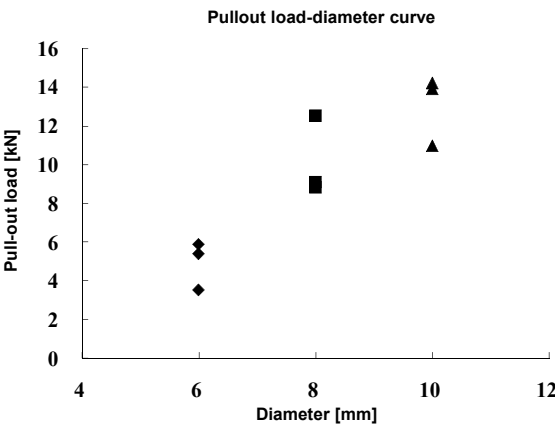


(a) Pullout load: CFRP rebar

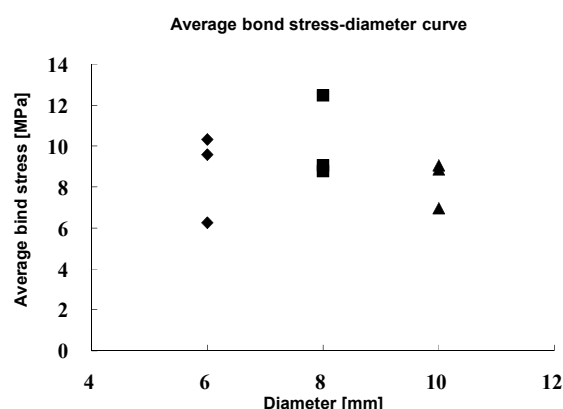


(b) Average bond stress: CFRP rebar

Figure 8: Bond characteristic of CFRP rebar



(a) Pullout load: AFRP rebar



(b) Average bond stress: AFRP rebar

Figure 9: Bond characteristic of AFRP rebar

4.3 Comparison with Deformed Bar

Average bond stress of deformed bar was 15.19 MPa in normal strength concrete. As shown in Figure 10, the CFRP rebar was 80.5% against that of the steel. And the AFRP rebar was 54.7 % .

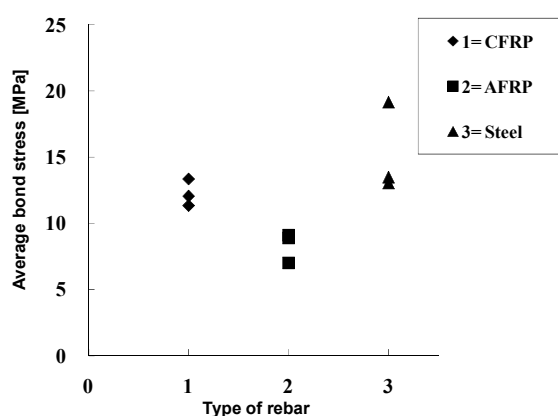


Figure 10: Comparison with deformed bar

5. CONCLUSIONS

In this study, 21 specimens were tested to figure out the influence of AFRP rebar and CFRP rebar to the bond strength with the variable of the diameter. The test results can be summarized as follows:

- (1) The bond strength was increased as diameter of rebar increased. In the contrast, average bond stress was decreased.

- (2) The bond strength of CFRP rebar is about 81% against that of deformed bar. And the bond strength of AFRP rebar is about 55%.

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