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Bond behavior of GFRP and steel bars in grouted spiral connections

Seyed jamal Aldin Hosseini[1)], Ahmad Baharuddin Abd. Rahman[2)], *Hyeon-Jong Hwang[3)], Seyed Kamal Aldin Hosseini[4)] and Su- Min Kang[5)]

[1), 3)] *Architectural Engineering, Konkuk University, Seoul, Korea*
[2)] *Faculty of Civil Engineering, Universiti Teknologi Malaysia, Johor, Malaysia*
[4)] *Department of Mineralogy and Geology, University of Debrecen, Debrecen, Hungary*
[5)] *Architectural Engineering, Soongsil University, Seoul, Korea*
[3)] hwanggun85@naver.com

ABSTRACT

The conventional grouted sleeve connections require long embedded length of reinforcement, which subsequently prevents the compact pouring of grout along the bar embedded length due to the construction error between the rebar and sleeve. For this reason, use of short embedded length is being popular for compact pouring of grout. In this study, the bond behavior of GFRP and deformed steel bars connected by a short embedment length in grouted spiral connection was investigated. Based on previous study, a total of 12 beam specimens were tested under flexural load to investigate the effects of spiral spliced confinement having various spiral diameters from 25 to 35 mm and grout strength of 60 MPa. The test results showed that the spiral confinement significantly improved the bond performance of GFRP bars and deformed steel bars.

1. INTRODUCTION

The effectiveness of the splice connection largely depends on the generated bond between the reinforcing bar and surrounding grout. Thus, a satisfactory splice connection should be able to provide the structural continuity due to the adequate bond strength along the short development length. The bond strength between deformed bars and surrounding concrete is affected by the following design parameters: embedment length, confinement, bar size, bar profile, bar spacing, bar casting position, concrete strengths, bar yield strength, and concrete cover (Thompson 2022, Pfister 1964).

The effect of confinement on the bond behavior of GFRP bars has not yet been studied sufficiently. Malvar (1995) carried out a wide research to study the bond-slip behavior of four commercially available FRP bars, and stated that the bar bond strength

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[1), 2), 4)] Post Doctor
[3), 5)] Professor

was significantly affected by the confinement. In contrast, according to the investigation of Wambeke and Shield (2006), the bond strength of FRP bars in concrete was not affected by confinement reinforcement. These contradictory results would be credited to the limited experimental data in the literature. Thus, the confinement effect on the bond behavior of the GFRP bars in grouted spiral connections needs to be studied.

In this study, a spiral confinement with various diameter was applied to spliced bars to generate confinement stress along the bar splices. The test results were compared with the predictions of current design codes.

2. TEST PROGRAM

2.1 Grouted spirally splice connection

Spiral reinforcement cage involves a spiral reinforcement and four welded high-strength deformed steel bars with 10 mm diameter (Fig. 1). By adding the 4Y10 spliced bars to the external diameter of the spiral, the tensile resistance mechanism is developed along the grouted connection.

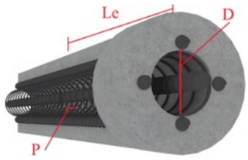

Fig. 1 Details of grouted spirally splice connection

Y10 or Y16 high-strength deformed steel bars were placed as the main bars at the splice connection. The material properties of three Y10 and Y16 bars are listed in Table 1.

Table 1 Material properties of steel reinforcing bars

Rebars	Yield stress (N/mm2)	Tensile strength (N/mm2)
Y10-1	740	777
Y10-2	722	814
Y10-3	678	760
Y16-1	570	667
Y16-2	571	663
Y16-3	560	655

In addition, in order to study the bond behavior of FRP rods, sand coated GFRP bars with the diameter of 16 mm were used. The fiber reinforcement was comprised of continuous E-glass fibers (Table 2).

Table 2 Material properties of GFRP reinforcement bars

GFRP bars	Maximum stress according to the manufacturer expectation (N/mm^2)	Measured tensile strength (N/mm^2)
GFRP 16-1	670	888
GFRP 16-2		883
GFRP 16-3		888

For the grouting of splice connections, Sika Grout-215, with the specified strength of more than 60 MPa at 28 days, was used in the grouted splice connections. Spirally splice connections were cast in the RC beam specimens to connect two main longitudinal bars. Ready-mixed concrete of Grade 40 was employed.

2.2 Beam specimens for flexural bond test

Flexural bond test was conducted based on the RILEM beam test. RC beams were applied to investigate the bond stress-slip behavior of the grouted spiral connection under flexural moment. The dimensions and reinforcements details of the test specimen are shown in Fig. 2. A steel hinge at the compression zone of the beam section is considered to connect two half-beams, and a main longitudinal bar passes through the tensile zone of the beam section. Two main longitudinal bars are spliced using the spiral connection at segment of the left beam. The test parameters are the diameter and pitch distance of the spiral reinforcement (Table 3).

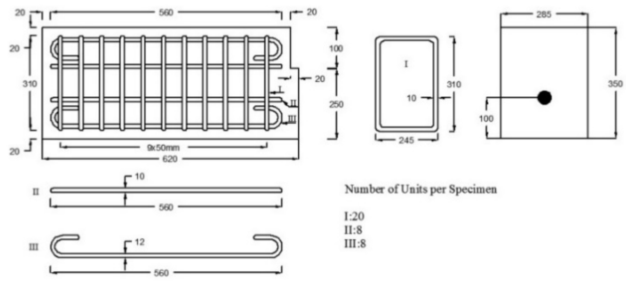

Fig. 2 Flexural pull-out test specimens

Table 3 Test results of grouted spirally splice connections

Specimens		Spiral diameter D_s (mm)	Pitch distance P_s (mm)	Peak strength P_u (kN)	Bond strength τ_{max} (MPa) unless specified	Slip (mm)	Failure modes
P15	P15 D25-S	25	15	55.4	14.70	2.20	Bar pull-out
	P15 D35- S	35	15	45.0	11.94	1.60	Bar pull-out
	P15 D25-F	25	15	26.8	7.10	0.70	Bar pull-out
	P15 D35- F	35	15	25.5	6.76	0.40	Bar pull-out
P25	P25 D25-S	25	25	53.5	14.19	2.01	Bar pull-out
	P25 D35- S	35	25	43.9	11.64	1.50	Bar pull-out
	P25 D25-F	25	25	25.8	6.84	0.60	Bar pull-out
	P25 D35- F	35	25	24.2	6.42	0.50	Bar pull-out
P35	P35 D25-S	25	35	52.1	13.82	2.00	Bar pull-out
	P35 D35- S	35	35	43.0	11.41	1.55	Bar pull-out
	P35 D25-F	25	35	23.8	6.30	0.50	Bar pull-out
	P35 D35- F	35	35	22.0	5.83	0.48	Bar pull-out

Note: Regarding the specimen nomenclature, the first letter P denotes the pitch distance, the second letter D denotes the spiral diameter, and the third letter S or F denotes the steel rebar or FRB bar, respectively. For all specimens: diameter of cylindrical grout D = 110 mm, connection length L_s= 160 mm, and embedded length L_e= 75 mm. Peak strength P_u = the maximum load prior to pull-out failure

2.3 Testing method

Two vertical loads (P) were applied symmetrically on each side of the ball joint (Fig. 3). The test setup and loading procedure followed the recommendations of RILEM (1970). The slip of the rebars was measured using the linear variable differential transformers

(LVDTs) at each load increment. Two set of LVDTs were installed on both active and passive ends of the specimens to evaluate the slip behavior of the main connected bar. As the pullout of main bars from the surrounding grout occurred, the LVDTs measured the slip as well as the elongation of the bar between the reference plate and the end of grout. It should be noted that the slip values are calculated on the loaded end and there are not any values of slip at unloaded end.

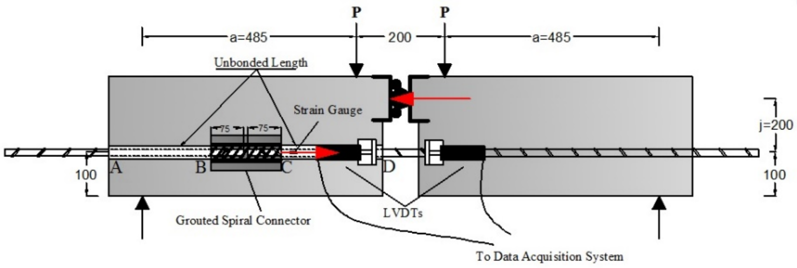

Fig. 3 Flexural pull-out test setup

3. TEST RESULTS AND DISCUSSION

Flexural pull-out beam was performed to evaluate the effect of spiral diameter on the bond behavior of steel reinforcing and GFRP bars. By assuming uniformly distributed bond stress, the average bond strength (τ) can be calculated from the test results. (ACI-116 2000, ACI-318 1962)

$$\tau = T \ / \ (\pi d_b L_e) \quad (1a)$$
$$T = Pa \ / \ j \quad (1b)$$

where *T* = tension force of the main longitudinal bar; d_b = diameter of the main longitudinal bar; L_e = bar development length; *P* = vertical load; *a* = shear span (485 mm); and *j* = moment lever arm at the beam section (200 mm). The average bond strength (τ) is shown in Table 3.

As the diameter of spiral confinement decreased from 35 to 25 mm, the bond strength of steel bars increased by 21~23%. This result proves that the diameter of spiral reinforcement is an effective parameter in increasing the bond strength between the main steel bars and grout. The increase of the bond strength was moderately low when the diameter of spiral confinement decreases from 35 to 25 mm. This result was confirmed by Malver (1995) and in opposite to the test results of Wambeke and Shield (2006).

4. CONCLUSIONS

In this study, 12 beam flexural pullout tests were tested to investigate the bond behavior of GFRP and deformed steel bars in grouted spiral connections. The primary findings were summarized as follow:

The diameter of spiral reinforcement has effect on the bond strength of the grouted spiral connection in both GFRP and deformed steel bars. The bond strength of deformed steel bars increased by 21~23% as the diameter of spiral reinforcement decreased from 35 to 25 mm. Instead, in the GFRP bars, the increase of the bond strength was moderately reduced to 5~8% as the diameter of spiral reinforcement decreased from 35 to 25 mm.

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