IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 05, Issue 07 (July. 2015), ||V1|| PP 39-42

Experimental Study on Behavior of Bond Stress with Lab-Spliced FRP Bar

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Abstract: This study performs an experimental works for estimation of bond strength of lap spliced FRP bars and deformed bars. Variables in this test with specimens of total 4 series planned are re-bar location, embedment length, covering depth, rebar diameter located at the bottom. From the experimental results, specimens with overlapping joints of CFRP bar and steel rebar showed that the different failure patterns depending on the ratio of embedment length and covering depth. In the design of overlap joints with different reinforcement, it should be a careful consideration of different stress transfer mechanism between each other.

Keywords: *Bond stress, FRP bar, Lap splice, Splitting failure, Concrete*

I. INTRODUCTION

Fiber-Reinforced Plastic (FRP) bar has higher design tensile strength than steel bar and outstanding characteristics such as light-weight, non-corrosion, and lower conductivity. And, current researchers evaluated flexural performances of flexural members using FRP and suggested the development length and splice length by using bonding failure test [1], [2].

This study has the main purpose to examine the quality of bonding failure in the lap spliced FRP and deformed bar. Variables in this test with specimens of total 4 series planned are re-bar location, embedment length (l), covering depth (C), rebar diameter (d_b) located at the bottom. And, this study describes the result of our review on the bonding strength of the lap-spliced FRP bar and the deformed bar located at the bottom

II. EXPERIMENTAL WORK

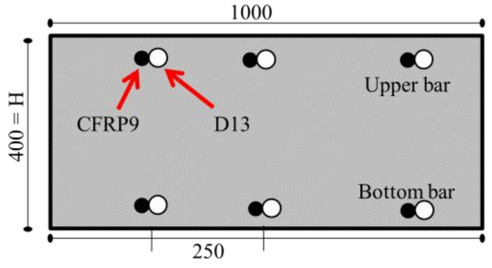
Total four specimens were planned as Table 1. GFRP (Glass-fiber reinforced plastic) bar and CFRP (Carbon fiber reinforced plastic) bar were used as FRP reinforcing bars. Specimens of series 1 and series 3 had overlapping joints of the same FRP bars. Specimens of series 2 and series 4 had overlapping joints of FRP bar and steel rebar.

Table 1 List of test specimens

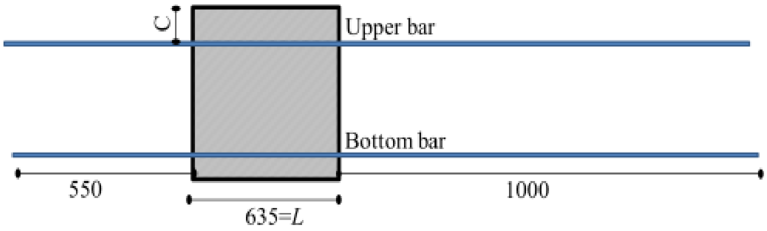
No	Name of Specimen	Width of specimen *(L)* [mm]	Covering depth *(C)* [mm]	l/d_b
1	G13-G13-L30	635	25.4	30
	G13-G13-L40			40
	G13-G13-L50			50
2	G13-D16-L30			30
	G13-D16-L40			40
	G13-D16-L50			50
3	C9-C9-L30	477	28.6	30
	C9-C9-L40			40
	C9-C9-L50			50
4	C9-D13-L30			30
	C9-D13-L40			40
	C9-D13-L50			50

*In specimen name, G: GFRP bar, C: CFRP bar, D: steel rebar, L: l/d_b

Fig. 1 shows details of test specimens (Specimens of No.4 series). Dimensions of the section are 1000mm×635mm or 1000mm×477mm, and the heights are 400mm. The ratio of embedment length and covering depth, l/d_b, is 30~50, and C/d_b is 2.5. Spacing of lap joints is 250mm or more. Only bottom bars were tested in this study.



(a) Dimensions and bar arrangements



(b) Details of section
Figure 1 Details of test specimens (No.4)

Specific design strength of concrete is 30 MPa. Table 2 and Table 3 show mechanical properties of the re-bars and the FRP used in the test specimens.

Table 2 Mechanical properties of steel rebar

Rebar Size	Cross-Sectional Area (mm^2)	Yield Strength (MPa)	Tensile Strength (MPa)
D13	126.6	526.9	634.1
D16	198.6	458.6	576.7

Table 3 Mechanical properties of FRP

FRP Bar Size	Cross-Sectional Area (mm^2)	Guaranteed Tensile Strength (MPa)	Elasticity Modulus (GPa)
G13(GFRP)	126.7	1059	46
C9(CFRP)	84.3	2188	150

Fig. 2 shows the installation status of specimens and the loading condition. 500kN hydraulic cylinder pulls the reinforcing bars penetrating through middle hole of cylinder. And it has been continued till FRP bars or steel bar have the tensile failure, or concrete by splitting failure in lapping zone is cracked.

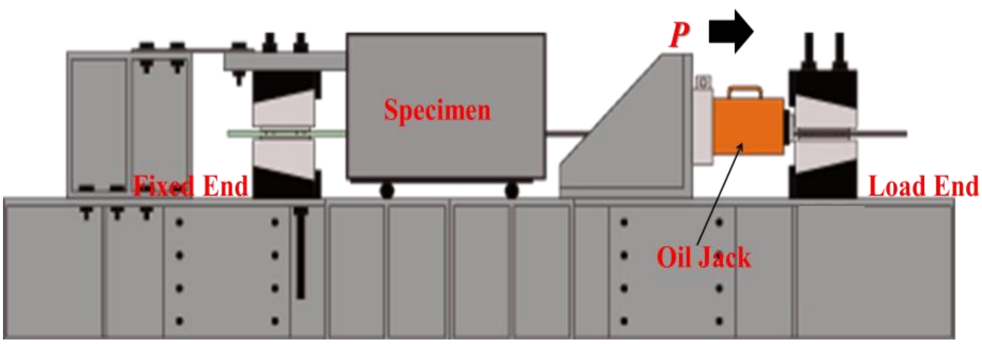


Figure 2 Test setup

The change of displacement was measured at loaded and fixed ends of overlapped-jointed reinforcing bars and after each LVDT was used. The cracks and failure shapes were recorded.

III. TEST RESULTS

(1) Failure patterns

Fig. 3 shows two typical failure patterns for specimens.

(a) Splitting failure (C9-D13-L30)

(b) Tensile failure of bar (C9-D13-L50)

Figure 3 Failure pattern

It had bond splitting failure for specimens of series 1~3. For specimens of series 4, they showed the different failure patterns depending on the ratio of embedment length and covering depth, l/d_b. Specimen C9-D13-L30 of which is 30, had bond splitting failure such as specimens of series 1~3. For specimen C9-D13-L40 and specimen C9-D13-L50, steel rebar was cut by tensile failure. This is because the tensile stress of the steel rebar is greater than the tensile strength before reaching the maximum bond stress of CFRP bar.

(2) Bond strength

Table 4 shows test results and Fig. 4 shows the relationship between bond stress and l/d_b for the test specimens. Table 4 and Fig. 4 indicated that bond strength of embedded reinforcement (τ_{max}) was decreased as the ratio of embedded length (l/d_b) increased. It did not exactly inversely proportional. Bond strengths of specimens of series 1 were greater than specimens of series 3. This indicates that the diameter of the reinforcing bars give a significant effect on the adhesion of the stress bars.

For specimens of series 2, bond strength of loaded ends ($\tau_{max.1}$) with smaller d_b was stronger than the other ($\tau_{max.2}$). In the design of overlap joints with different reinforcement such as specimens of series 2 and series 4, it should be a careful consideration of different stress transfer mechanism between each other.

IV. CONCLUSION

Experimental study was performed for estimation of bond strength of lap spliced FRP bars and deformed bars, and the results are as follows;

1) In most specimens, it had bond splitting failure. For specimens with overlapping joints of CFRP bar and steel rebar, they showed the different failure patterns depending on the ratio of embedment length and covering depth.

2) Bond strength of embedded reinforcement was decreased as the embedded length increased and bond strength of bars with smaller d_b was stronger than the other.

3) In the design of overlap joints with different reinforcement such as specimens of series 2 and series 4, it should be a careful consideration of different stress transfer mechanism between each other.

Table 4 Test results

No	Specimens	P_{max} kN	$\tau_{max.1}$ (MPa)	$\tau_{max.2}$ (MPa)	τ_{max} (MPa)	Failure mode
1	G13-G13-L30	67.5	4.4	4.4	4.4	B-S
	G13-G13-L40	58.7	2.9	2.9	2.9	B-S
	G13-G13-L50	70.0	2.8	2.8	2.8	B-S
2	G13-D16-L30	91.2	6.0	4.8	6.0	B-S
	G13-D16-L40	99.1	4.9	3.9	4.9	B-S
	G13-D16-L50	69.6	2.7	2.2	2.7	B-S
3	C9-C9-L30	53.3	6.2	6.2	6.2	B-S
	C9-C9-L40	43.0	3.8	3.8	3.8	B-S
	C9-C9-L50	49.5	3.5	3.5	3.5	B-S
4	C9-D13-L30	78.7	9.8	4.8	9.8	B-S
	C9-D13-L40	73.5	-	-	-	D-T
	C9-D13-L50	63.4	-	-	-	D-T

Note. $\tau_{max.1}$: bond strength (Fixed end), $\tau_{max.2}$: bond strength (Load end), τ_{max}: higher value between $\tau_{max.1}$ and $\tau_{max.2}$, B-S : bond splitting failure, D-T : tensile failure of bar

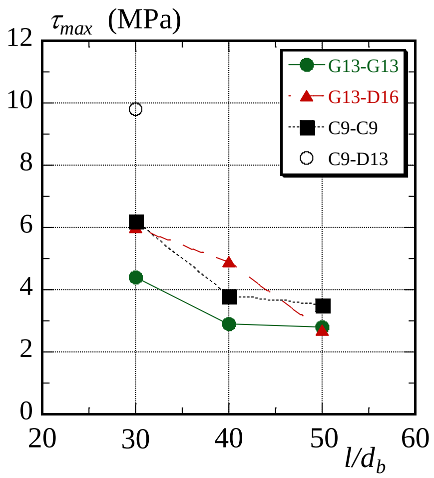


Figure 4 □$_{max}$ and l /d_b relations

V. ACKNOWLEDGEMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2010-0025550), and by sabbatical program of Hanbat National University (2011).

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