

A Study on the Bond Strength between High Performance Concrete and Reinforcing Bar

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Abstract

As a preliminary study for the erection of floating structures using high performance concrete, this paper examines the bond characteristics between concrete and the reinforcing bar. Since the floating structure is constructed in aquatic environment, corrosion of the reinforcing steel is likely to develop more prematurely than in onshore structure in case of concrete cracking. A solution to this corrosion problem could use FRP rebar instead of steel reinforcement. To that goal, an experimental study is conducted on the concrete-FRP bond strength to verify if such FRP rebar develops performance comparable to the conventional steel rebar. A series of tests are performed considering the bond length of ordinary steel rebar and G-FRP rebar as test variable with respect to the strength of concrete, and the results are presented.

Keywords

FRP Reinforcement, High Performance Concrete, Bond Strength, Concrete Strength, Bond Length

1. Introduction

The existing steel floating structures are exposed to the specific environmental problems encountered by large marine structures including corrosion and the need for periodic repainting to prevent corrosion. Besides, the existing concrete floating structures are prone to problems like the increased height of the structure to secure the buoyancy necessary to lift the excessive weight of the structure and the corrosion of inner reinforcement caused by the intrusion of seawater provoked by the lack of watertightness.

An alternative to cope with this corrosion problem could replace the conventional steel reinforcement arranged in concrete by GFRP bars. Therefore, a series of tests are conducted to evaluate the bond performance between concrete and GFRP. Numerous results have been reported on the bond performance between concrete and the reinforcing steel, and studies have been and are still being conducted on the bond between concrete and

FRP [1] [2]. For example, Habel [3] carried out a study on the bond strength and control of cracks between the steel reinforcement and concrete by the fiber reinforcement in ultra high performance concrete (UHPC). And, Holschemacher *et al.* [4] studied the bond strength according to the age of UHPC, the diameter of rebar, the thickness of cover and the loading speed.

As a preliminary study for the application of SUPER Concrete (SC, compressive strength range: 80 - 180 MPa), the high performance concrete developed by the Korea Institute of Civil Engineering and Building Technology (KICT), to floating structures, this paper examines experimentally the bond performance between SC and conventional reinforcing steel, and between SC and GFRP bar. To that goal, tests are performed on specimens fabricated taking the compressive strength of the concrete member, the bond length and the type of reinforcing bar as test variables.

2. Bond Test

Bond strength tests are performed considering the strength of concrete and bond length of the reinforcement as test variables to evaluate the bond strength between concrete and the reinforcing bar at the intersegmental connection of the floating structure using SC. For the tests, the diameter of the steel and FRP bars is set to 10 mm, and the target strength of concrete is set to 40, 80, 100, and 120 MPa. Loading is applied at speed of 1.3 mm/min and, the bond length is varied as 40, 70, 100, and 130 mm.

The evaluation of the bond characteristics between SC and the reinforcement is conducted by modifying partially the test method recommended by RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures) [5]. RILEM proposes to use cubic specimens with side length being the minimum between 200 mm and $10d_s$, where d_s is the diameter of rebar. In this study, it was considered that the minimum length of 200 mm is appropriate for ordinary strength concrete. Accordingly, the concrete cube specimens were fabricated with side length of 200 mm and were steel-reinforced to prevent failure of concrete before the occurrence of bond failure as shown in Figure 1. Table 1 lists the types of the specimens and the corresponding test variables. Figure 2 displays the disposition of the specimens and deflectometers.

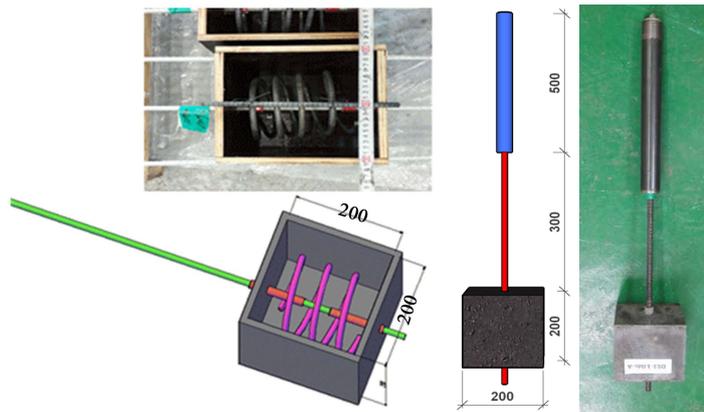


Figure 1. Shape of specimen.

Table 1. Type of specimens and corresponding test variables.

Reinforcement		Concrete compressive strength (MPa)	Bond length (mm)	Number of specimens
Steel	D10 (φ10-steel)	40, 80, 100, 120	40	5 ea. per strength
		40	40, 70, 100, 130	5 ea. per length
GFRP	D9.5 (φ9.5-GFRP)	80	40, 70, 100, 130	5 ea. per length
		100	40, 70, 100, 130	5 ea. per length
		120	40, 70, 100, 130	5 ea. per length
			Total	100



Figure 2. View of specimens and layout of deflectometers.

As shown in Figure 2, a deflectometer is installed at each top, center and bottom to measure respectively the concrete-reinforcement displacement, the relative displacement between concrete and the anchorage, and the displacement of the anchorage.

Figure 3 plots the deflection history caused by the bond failure of the reinforcement with respect to the applied load for the concrete compressive strength of 40 MPa. In Figure 3, clear difference can be observed in the behavior of steel reinforcement (Figure 3(a) and Figure 3(b)) and GFRP reinforcement (Figure 3(c) and Figure 3(d)). In Figure 3, DT-1 plots the response measured by the deflectometer installed at the top and represents the relative displacement between the concrete block and the reinforcement, DT-2 is the relative displacement between the concrete block and the anchorage, DT-3 is the absolute displacement of the anchorage and, UTM stands for the actual displacement of the UTM (Universal Testing Machine). For curve DT-1 showing the bond performance, clear difference can be identified in the behavior of the steel reinforcement and GFRP. Concretely, the relative displacement between the concrete block and the steel reinforcement increases linearly until brittle bond failure whereas the relative displacement between the concrete block and GFRP starts with a linear increase to show ductile bond failure. Besides, curve DT-2 shows identical pattern to that of UTM. Especially, the part in which the slope of the curve varies indicates simultaneous occurrence of bond failure and tensile failure of the steel reinforcement.

3. Test Results

The average bond stress τ at any stage during loading is calculated using Equation (1).

$$\tau = \frac{P}{\pi d_b l_b} \quad (1)$$

where P is the pullout load, d_b is the diameter of the rebar, and l_b is the embedment length of the rebar.

Table 2 arranges the bond test results of the steel and GFRP reinforcement. Figure 4 plots the hysteresis of the bond force per strength of concrete. It can be seen that the bond force of the steel reinforcement keeps a constant level even when the strength of the block increases. Besides, the bond force of the GFRP reinforcement increases with higher strength of the block and longer bond length as expected.

Figure 5 plots the bond force with respect to the compressive strength of concrete and bond length. The bond strength of the steel reinforcement is seen to range between 35 and 37 MPa and that of the GFRP rebar between 15 and 21 MPa. For the GFRP reinforcement, it was expected that the bond stress would increase proportionally to the increase of the strength of concrete and bond length but the strength appeared to keep a definite level without steep increase. This result can be explained by the occurrence of failure due to the cover of the GFRP itself prior to the bond failure according to the lengthening of the bond length between the concrete block and

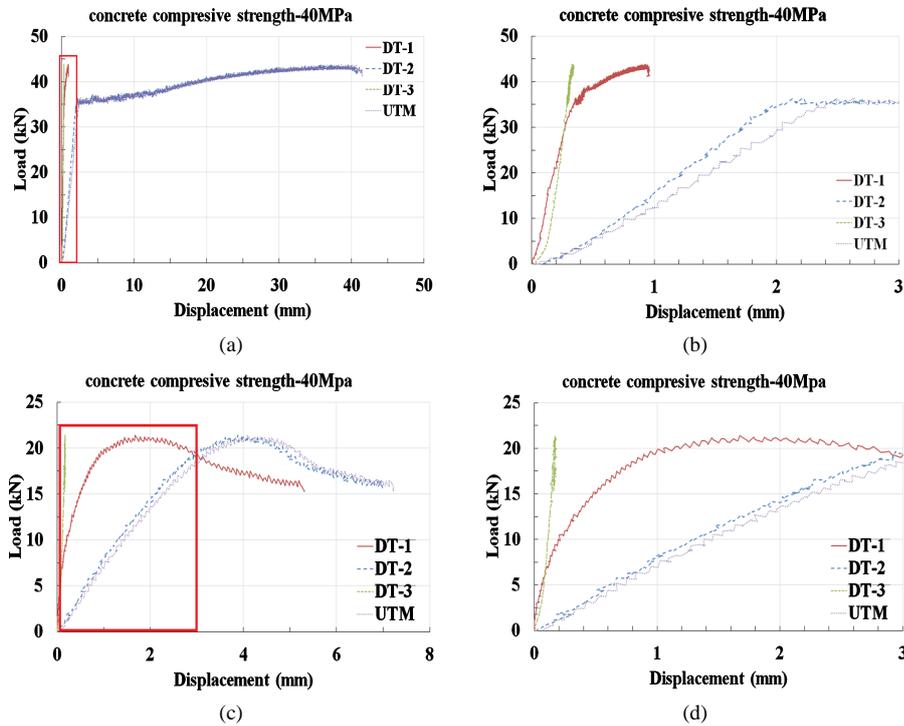


Figure 3. Comparison of experimental bond performance between steel and GFRP reinforcement. (a) Concrete-steel rebar load-displacement curves; (b) Zoom up of (A); (c) Concrete-GFRP rebar load-displacement curves; (d) Zoom up of (B).

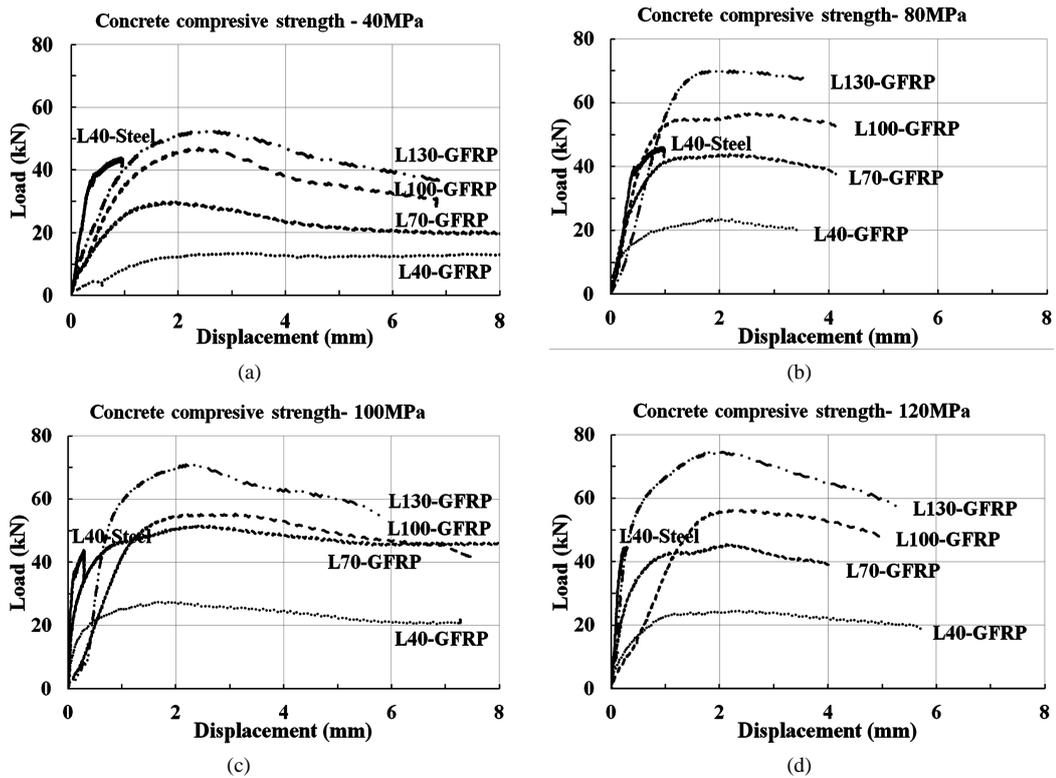


Figure 4. Bond force-deflection hysteresis per compressive strength of concrete. (a) Concrete compressive strength of 40 MPa; (b) Concrete compressive strength of 80 MPa; (c) Concrete compressive strength of 100 MPa; (d) Concrete compressive strength of 120 MPa.

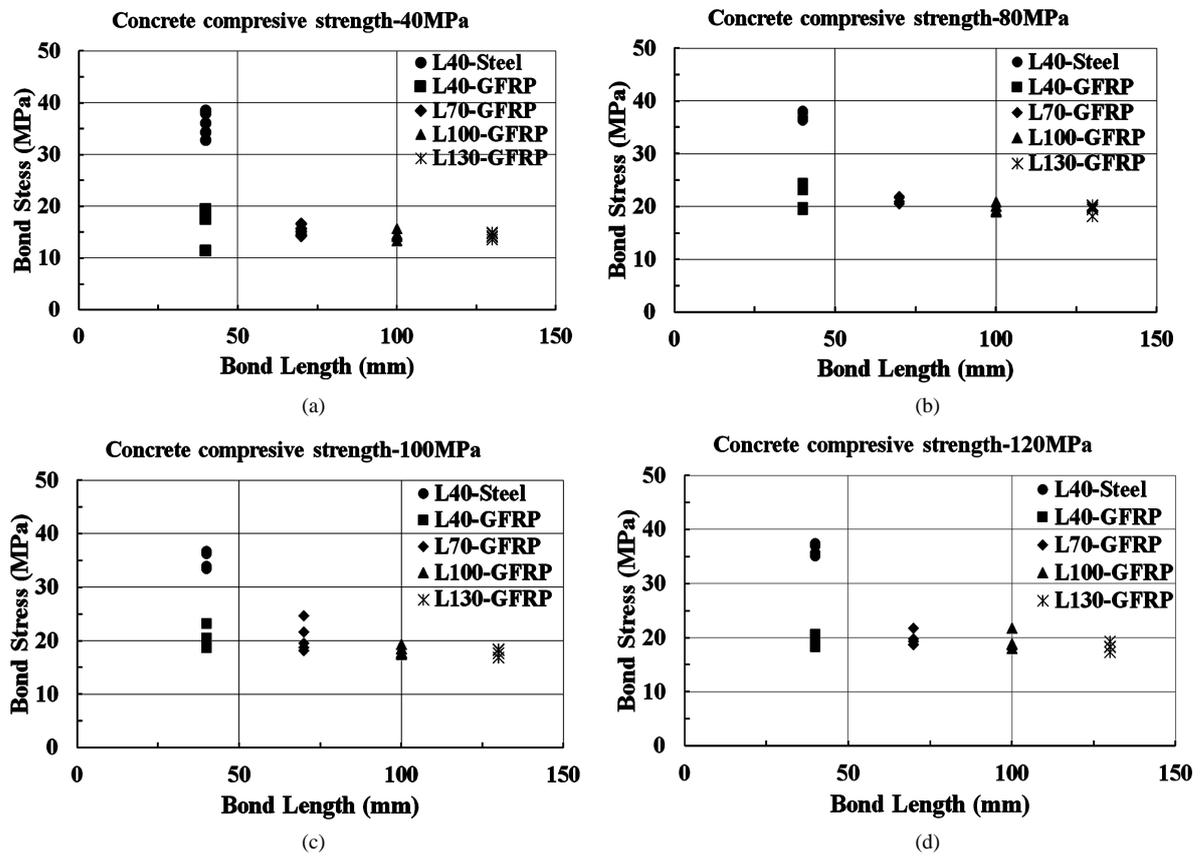


Figure 5. Bond stress-bond length relation per compressive strength of concrete. (a) Concrete compressive strength of 40 MPa; (b) Concrete compressive strength of 80 MPa; (c) Concrete compressive strength of 100 MPa; (d) Concrete compressive strength of 120 MPa.

Table 2. Bond strength (average).

Rebar type	Compr. strength of concrete (MPa)	$4d_s$		$7d_s$		$10d_s$		$13d_s$	
		Max. load (kN)	Bond strength (MPa)						
Steel	40	43.068	35.89						
	80	44.552	37.13						
	100	42.392	35.33						
	120	43.698	36.42						
GFRP	40	20.206	16.93	31.852	15.25	43.118	14.45	55.596	14.34
	80	25.302	21.21	44.210	21.17	59.204	19.85	75.890	19.57
	100	23.978	20.10	42.876	20.53	54.116	18.14	69.430	17.90
	120	23.486	19.68	41.074	19.67	57.450	19.26	71.104	18.34

GFRP reinforcement. Therefore, it seems that GFRP does not experience significant change when the critical bond length is secured even under increase of the bond length and compressive strength of concrete.

4. Conclusion

As part of a research for the erection of floating structures using high performance concrete, this paper presented a preliminary experimental study on the bond characteristics between concrete and the reinforcing bar. Tests were performed to verify the performance of steel and GFRP reinforcements taking the compressive strength of concrete and the bond length as test variables. For the steel rebar, tensile failure of the reinforcement occurred before bond failure since sufficient bond length was applied. Therefore, it appeared that the bond performance

of the steel reinforcement was secured. For the GFRP rebar, it was verified that the cover of GFRP failed prior to the bond failure even under increase of the bond length and compressive strength of concrete, because the specimens secured sufficient bond length. Additional study on the critical bond length of GFRP should be conducted in the future.

Acknowledgements

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