Direct Tensile Test of GFRP Bar Reinforced Concrete Prisms

Choi, Dong-Uk;[*] Lee, Chang-Ho;[*] and Ha, Sang-Su[**]

Abstract

Uniaxial tension test of Glass Fiber Reinforced Polymer (GFRP) bar reinforced concrete prisms was performed. The objective was to investigate the adequate cover thickness of the GFRP rebars. The tension stiffening effect of GFRP bar reinforced concrete was also studied. The test variables included rebar types (conventional steel rebar and two different GFRP rebars) and cover thicknesses (five different cover thicknesses ranging between 1-3db). Normal strength concrete was used. Cracking patterns on concrete surface and cracking loads were carefully observed during the direct tensile test. The test results indicated that the adequate cover thickness of the GFRP rebars may even be larger than that of the steel rebars and that the cover thickness of 2db commonly specified for the GFRP rebars may not be large enough. The tension stiffening effect of the GFRP rebars was also quantified and documented from the test results.

---

* School of Architecture, Hankyong National University ** STRESS, Hanyang University

1. INTRODUCTION

The GFRP rebars can be used instead of conventional steel reinforcing bars in structures subjected to aggressive environments such as marine structures, structures exposed to deicing salts, and combinations of moisture, temperature, and chlorides. One of the important subjects in the research of the GFRP rebars is the development and lap splice lengths because the GFRP rebars typically require the lengths significantly longer than those for the steel rebars. Choi et al. studied the lap splice lengths of the GFRP rebars using beam specimens.[1] The employed cover thickness of the GFRP rebars was 2db following recommendations of reference 2. The lap splice lengths ranging between 10-70db were tested while extensive splitting was typically observed during testing indicating that the cover depth of 2db may not be sufficiently large. Although a large cover thickness is not necessary for the GFRP rebars because the bars are noncorrosive, the test results of Choi et al. reveal that GFRP rebars may still need the cover depths larger than 2db.

2. PREPARATION FOR TEST

2.1 Materials

Conventional steel deformed reinforcing bar and two different GFRP bars, one with deformation at regular spacing (noted as "FS" in this study) and the other with sand coated textured surface (noted as "FSC"), were used for tests. Material properties of the GFRP rebars are summarized in Table 1. Yield strength of the D13 steel rebar (noted as "R") was 470MPa and the elastic modulus was 200GPa. Concrete compressive strength was 31MPa.

Table 1 Material Properties of GFRP Bars

Bar type	Diamter, mm	Area, mm^2	f_{ult} MPa	E, GPa	Resin	Fiber	Fiber content, %	Remarks
Deformed	12.7	145	690	40.8	Vinyl Ester	E-glass	70.0	FS
Sand coated	12.7	129	617	42.0	Vinyl Ester	E-glass	70.0	FSC

2.2 Test Specimens

Fifteen direct tensile tests of reinforced concrete prisms were completed. The concrete prisms were reinforced with a rebar at center. Test variables were bar types (FS, FSC, and R) and the cover thicknesses (1, 1.5, 2, 2.5, and 3db). The length of the concrete prisms was 760mm while the cross-sectional area remained the same. Fig. 1 shows the schematics of the direct tensile test.[3]

Table 2 Summary of Test Variables

Cover thickness	Cross section, mm x mm	Area, mm^2	Length, mm	Remarks
3db	91 x 91	8,280	760	Five tests of conventional steel rebar (R), GFRP bar with deformation at regular spacing (FS), and GFRP rebar with sand coated textured surface (FSC), respectively.
2.5db	78 x 106	8,280	760	
2db	65 x 127	8,280	760	
1.5db	52 x 159	8,280	760	
1db	39 x 212	8,280	760	

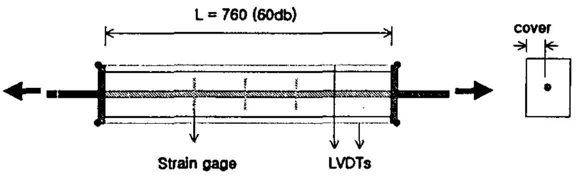


Fig. 1 Direct Tensile Test Setup

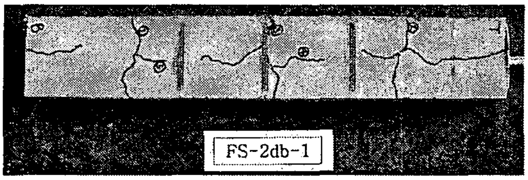


Fig. 2 Crack Pattern after Completion of Test

2.3 Test Setup

A 1200-kN U.T.M. was used for test which provided the load data. The change in length of the concrete prisms were monitored using 2 LVDTs placed symmetrically in the longitudinal direction as shown in Fig. 1. Three pairs of electronic strain gages were installed on the side surfaces of the concrete prism in the transverse direction in an attempt to detect the onset of cracking that develops during test.

3. TEST RESULTS

Development of cracks on the concrete surfaces was carefully monitored during test. The onset of both transverse and splitting cracks was visually monitored and recorded. Signals from the electronic devices such as LVDTs and strain gages were also used to verify these cracking loads. As the load increased, a transverse crack typically developed first. This was followed by another transverse crack or a splitting typically starting from existing transverse crack. A typical crack pattern after completion of test is shown in Fig. 2.

Table 3 Summary of Test Results: Cracking loads

Specimen index	Transverse crack, kN	Splitting crack, kN	Specimen index	Transverse crack, kN	Splitting crack, kN	Specimen index	Transverse crack, kN	Splitting crack, kN
FS-1db	10.6	14.1	FSC-1db	10.2	12.1	R-1db	10.9	16.0
FS-1.5db	12.5	19.0	FSC-1.5db	11.2	14.2	R-1.5db	12.2	23.7
FS-2db	13.5	19.0	FSC-2db	15.4	17.0	R-2db	12.9	29.0
FS-2.5db	18.6	35.0	FSC-2.5db	12.3	15.8	R-2.5db	13.7	34.7
FS-3db	12.7	18.2	FSC-3db	13.8	17.9	R-3db	12.0	39.8

The first loads at which a transverse crack initiated in specimens are compared in Fig. 3 between different rebar types. Fig. 3 indicates that the first transverse cracking loads are in general in the range of 10-15kN regardless of the rebar types. There is a tendency that the first transverse cracking loads increase a little with increasing cover thickness as shown. Loads at which a splitting occurred first are shown in Fig. 4. In Fig. 4, the first splittings typically occurred in the load range of 10-20kN for the GFRP rebars. The loads for this first splitting do not increase sharply with increasing cover thickness. On the other hand, the first splitting occurred in the load range of 15-40kN for the steel rebars. The first splitting loads sharply increase with increasing cover thickness as shown. Since the splitting crack occurs because of the tensile stress developing in the radial direction by bearing of the bar deformations on concrete, the test results seem to indicate that the splitting stress may even be more severe in the GFRP rebars than in the deformed steel rebars.

4. CONCLUSIONS

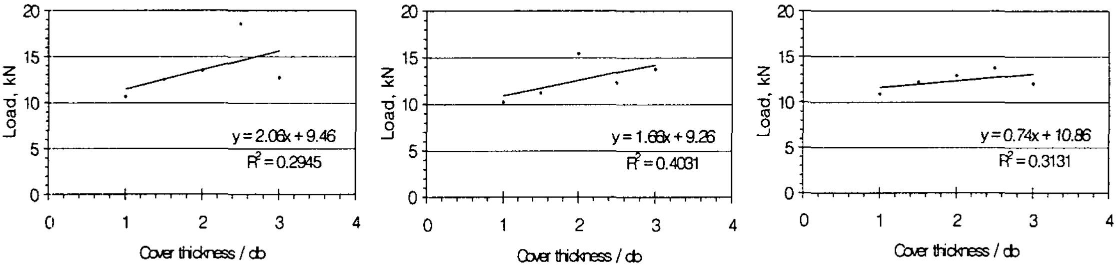
The following conclusions are drawn from this study although the test results are tentative because of the limited number of tests.

(1) The first transverse cracks initiated in the stress range of 12-18MPa in the normal strength concrete (f_{cu} = 31MPa).

(2) The first splitting initiated in the axial stress range of 12-24MPa for the GFRP rebars. On the other hand, the first *splitting occurred in the range of 18-48MPa for the steel rebars.*

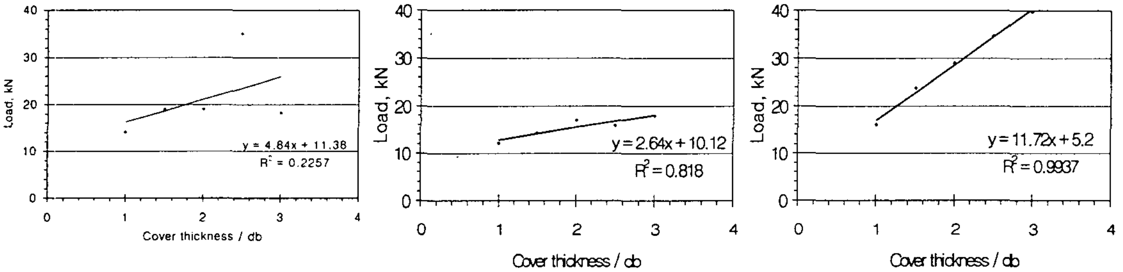
(3) Test results indicate that the splitting stress may even be more severe in the GFRP rebars than in the deformed

steel rebars. The cover thickness of 2db commonly specified for the GFRP rebars are not sufficiently large enough.



(a) GFRP: FS (b) GFRP: FSC (c) Deformed steel: R

Fig. 3 Cover Thickness vs. Transverse Cracking Load



(a) GFRP: FS (b) GFRP: FSC (c) Deformed steel: R

Fig. 4 Cover Thickness vs. Split Cracking Load

Ackowledgement

Authors gratefully acknowledge that this project was funded by Korea Institute of Construction Technology for the project titled as "Design and Construction Technology for Concrete Structures Using Advanced Composite Materials - FRP Rebars, Tendons, and Grids."

References

1. Choi, D.-U. et al. "Lap Splice Length of Glass Fiber Reinforced Polymer Reinforcing Bars with Different Surface Design," Proceedings of the KCI Fall Convention, 2004, pp.449-452.
2. ACI Committee 440 "Guide for the Design and Construction of Concrete Reinforced with FRP Bars," ACI 440.1R-03, 2003.
3. Kim Woo and Lee K.-Y. "Tension Stiffening Effect of High-Strength Concrete in Axially Loaded Members," Proceedings of the First International Conference of Asian Concrete Federation, Oct. 2004, Chiang Mai, Thailand, pp.228-237.