탄소섬유시트를 이용한 I형 PFRP 부재의 휨보강 효과

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The Flexural Strengthening Effect of I-Shape PFRP Member Using Carbon Fiber Sheet

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Abstract: In recent years, fiber reinforced polymer plastic composites are readily available in the construction industry. Fiber reinforced polymer composite has many advantages such as high specific strength and high specific stiffness, high corrosion resistance, light-weight, magnetic transparency, etc. In this paper, we present the result of investigation pertaining to the flexural behavior of flange strengthened I-shape pultruded fiber reinforced polymer plastic (PFRP) member using carbon fiber sheet (CFRP sheet). Test variable is consisted of the number of layers of strengthening CFRP sheet from 0 to 3. From the experimental results, flexural strengthening effect of flange strengthened I-shape PFRP member using CFRP sheet is evaluated and it was found that 2 layers of strengthening CFRP sheet are appropriate considering efficiency and workability.

Key Words: Pultrusion FRP, Carbon fiber sheet, Strengthening method, Experiment, Strengthening effect

1. INTRODUCTION

Strengthening methods of flexural members such as reinforced concrete (RC) beam and slab are already developed and they are in use for many field applications. Among the methods, externally bonded fiber reinforced polymeric plastic (FRP) sheets and plates are currently being studied and applied for the repair and strengthening of structural concrete members around the world (Meier 1997; Lee et al., 2012a; Choi et al., 2012). Wet-laid carbon FRP (CFRP) sheets and precured plates, in particular, have been the object of

much interest in the civil engineering field for applications on beams, slabs, and columns due to their excellent stiffness, strength, and durability. Repair and strengthening with CFRP sheets or plates provide an attractive alternative to the use of steel plates, which is more labor- and equipment-intensive (Tripi et al., 2000). And then the design guideline (ACI Manual of Concrete Practice, 2008) included design for the repair and strengthening of structural concrete members developed by the American Concrete Institute (ACI).

However, the study on strengthening of glass fiber reinforced polymeric plastic (glass fiber and polyester

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resin) structural member using carbon fiber sheet (carbon fiber and epoxy resin) is not available at present.

we present the experimental result of investigation pertaining to the flexural behavior of flange strengthened I-shape pultruded fiber reinforced polymer plastic (PFRP) structural member using CFRP sheet. In the experiment, test variable is the number of layers of strengthening CFRP sheet from 0 to 3. Failure loads and maximum deflections for each specimen were measured or observed.

2. MECHANICAL PROPERTIES

1. Carbon Fiber Sheet

Carbon fiber sheets used in the test are products manufactured with the carbon fiber woven fabric and epoxy resin by the Hankuk Carbon Co., Ltd. in Korea. Tension tests of the CFRP sheets were conducted according to the KS M ISO 527-4 at the Structural Engineering Laboratory at Hongik University in Seoul, Korea. Total of five test specimens are uni-axially loaded up to failure with a constant loading speed of 3 mm/min at a constant room temperature of 23°C. The tension test set-up is shown in Fig. 1 and the stress-strain relationship is shown in Fig. 2. The test results are summarized in Table 1.

Fig. 1 Tension Test Set-up for CFRP

2. I-shape PFRP Structural Member

I-shape PFRP structural member used in the test is manufactured by the pultrusion process in the Kyungsin Fiber Co., Ltd. in Korea. Total of seven test specimens were tested according to the KS M ISO 527-4 at the Structural Engineering Laboratory at Hongik University in Seoul, Korea. All the specimens are loaded up to failure with a constant loading speed of 3 mm/min at a constant room temperature of 23°C. The tension test set-up is shown in Fig. 3 and the stress-strain relationship is shown in Fig. 4. The test results are summarized in Table 2.

Fig. 2 Stress-Strain Relationship for CFRP

Table 1. Mechanical Properties of CFRP Sheet (Lee, 2013)

Specimen Designation	Area (mm ²)	Strength (MPa)	Modulus of Elasticity (GPa)
CFP-1	26.55	N/A	N/A
CFP-2	26.25	2,104.76	179.27
CFP-3	27.46	2,491.21	173.33
CFP-4	25.74	2,726.35	169.98
CFP-5	26.50	2,504.01	166.99
Average	26.49	2573.86	170.10

Fig. 3 Tension Test Set-up for PFRP

Fig. 4 Stress-Strain Relationship for PFRP Member (Lee, 2010; Park, 2011)

Table 2. Mechanical Properties of I-shape PFRP Member (Lee, 2010; Park, 2011)

Specimen Designation	Area (mm ²)	Strength (MPa)	Modulus of Elasticity (GPa)
PFRP-1	240.24	291.03	32.94
PFRP-2	242.73	373.42	36.54
PFRP-3	229.15	457.53	32.40
PFRP-4	242.15	535.55	39.66
PFRP-5	244.16	348.64	30.87
PFRP-6	244.26	305.93	29.46
PFRP-7	250.09	523.85	29.36
Average	241.87	481.38	33.28

3. FLEXURAL TEST

1. Test Specimen Design and Preparation

The test specimen of flange strengthened I-shape PFRP member with carbon fiber sheet was prepared by the Hankuk Carbon Co. Ltd. The material properties of I-shape PFRP member are obtained by the test conducted at the Structural Engineering Laboratory in Hongik University. Designation of test specimens is summarized in Table 3.

「1.05-0~1 ply」 specimens are tested to estimate the difference between no strengthening and strengthening with 1 ply carbon fiber sheet. 「0.60-1~3 ply」 specimens are tested to estimate the flexural strengthening effect of the number of carbon fiber sheet. The cross-sections of each specimen with or without flange strengthening are shown in Fig. 5. The flexural test specimens are also shown in Fig. 6.

Table 3. Test Specimen of Flexural Test (Lee, 2013)

Specimen Designation	Total Length (mm)	No. of CFRP Sheet Ply
1.05-0 ply-1	1,050	0
1.05-0 ply-2		
1.05-0 ply-3		
1.05-1 ply-1		1
1.05-1 ply-2		
1.05-1 ply-3		
0.60-1 ply-1	600	1
0.60-1 ply-2		
0.60-1 ply-3		
0.60-2 ply-1		2
0.60-2 ply-2		
0.60-2 ply-3		
0.60-3 ply-1		3
0.60-3 ply-2		
0.60-3 ply-3		

1.05-0 ply-1

Total Length of Specimen
 No. of CFRP Sheet Ply
 No. of Specimen

Fig. 5 Cross-section of Specimen (Lee et al., 2012b)

(a) Specimen without strengthening (1.05m)

(b) I-shape PFRP member strengthened with CFRP sheet (1.05m)

(c) I-shape PFRP member strengthened with CFRP sheet (0.60m)

Fig. 6 Flexural Test Specimen (Lee, 2013)

2. Flexural Test Scheme

To estimate the flexural strength of I-shape PFRP member and flange strengthened I-shape PFRP member with carbon fiber sheet, flexural test on both types of test specimens was conducted. For the flexural strength tests, the specimen was installed and loaded using the Universal Testing Machine (UTM) with 1,000kN capacity. A total of 15 specimens, 3 specimens for each type, are tested under four-point bending loads according to the method suggested by ASTM D 790-023. All the specimens are loaded up to failure with a constant loading speed of 1 mm/min. Flexural test scheme and set-up are shown in Fig. 7. Strains along the longitudinal direction of the specimen and the transverse deflection at the center of the span of the specimen are measured by strain gages and wire gages, respectively, in the flexural tests. One of the failed specimens is shown in Fig. 8. Summary of average flexural test results is presented in Table 4.

(a) 1.05-1 ply

(b) 0.60-1 ply

Fig. 7 Flexural Test Scheme and Set-up (Lee, 2013)

Fig. 8 Failure of Specimen (Lee et al., 2012b)

Table 4. Result of Flexural Test (Lee, 2013)

Specimen Designation	Load (kN)	Deflection (mm)	Flexural Strength (MPa)	Flexural Stiffness ($kN \cdot m^2/m^3$)
1.05-0 ply-1	228.09	6.40	73.61	35.64
1.05-0 ply-2	215.74	6.00	69.62	35.96
1.05-0 ply-3	229.16	5.80	79.95	39.51
Average	224.33	6.07	74.39	36.96
1.05-1 ply-1	236.99	5.60	76.48	42.32
1.05-1 ply-2	229.04	5.80	73.91	39.49
1.05-1 ply-3	233.68	5.30	75.41	44.09
Average	233.24	5.57	75.26	41.87
0.60-1 ply-1	N/A			
0.60-1 ply-2	107.30	1.3	36.46	82.54
0.60-1 ply-3	166.82	1.9	56.68	87.80
Average	137.06	1.6	46.57	85.66
0.60-2 ply-1	248.57	1.8	84.45	138.09
0.60-2 ply-2	253.89	1.9	87.79	133.63
0.60-2 ply-3	204.89	1.7	69.61	120.52
Average	235.78	1.8	80.62	130.99
0.60-3 ply-1	209.54	2.1	71.79	99.78
0.60-3 ply-2	219.50	1.7	74.58	129.12
0.60-3 ply-3	243.06	1.8	82.58	135.03
Average	224.03	1.9	76.32	117.91

4. TEST RESULTS

1. Strengthening Effect

「1.05-0~1 ply」 specimens (total length is 1.05m) were analyzed to estimate the strengthening effect.

The maximum load of 1.05-1 ply specimens increased by 1.7% compared with 1.05-0 ply specimens. The maximum deflection of 1.05-1 ply specimens decreased by 8.2% compared with 1.05-0 ply specimens. As a result, the increase rates of flexural strength and flexural stiffness are 4% and 13%, respectively. Load-deflection relationship is shown in Fig. 9.

(a) 1.05-0 ply

(b) 1.05-1 ply

Fig. 9 Load-Deflection Relationship of 1.05-0 ply and 1.05-1 ply Specimens (Lee, 2013)

2. Effect of the Number of CFRP Sheet

「0.60-1~3 ply」specimens (total length is 0.60m) were analyzed to estimate the flexural strengthening effect depending on the number of carbon fiber sheet attached.

The maximum load of 0.60-2 ply specimens increased by 49.5% compared with 0.60-1 ply specimens. The maximum deflection of 0.60-2 ply specimens increased by 12.5% compared with 0.60-1 ply specimens, respectively. As a result, the increase rates of flexural strength and flexural stiffness are 73.1% and 50.72%. In addition, the maximum load of 0.60-3 ply specimens decreased by 5% compared with 0.60-2 ply specimens. The maximum deflection of 0.60-1 ply specimens increased by 5.5% compared

with 0.60-2 ply specimens. Flexural stiffness and flexural strength of test specimen with 2 ply carbon fiber sheet were much higher than that of the specimen strengthened with 1 ply. On the other hand, flexural strengthening effect of the test specimen with 3 ply carbon fiber sheets was less than that of 2 ply strengthened one. Poor adhesion between each carbon fiber layers is suspected to be the main reason of flexural stiffness reduction. Difference of flexural stiffness and flexural strength with respect to the number of carbon fiber sheet layers were shown in Fig. 10 and Fig. 11, respectively.

Fig. 10 Flexural Strength-Number of Strengthening Layers Relationship of 0.60-1 ply, 0.60-2 ply, and 0.60-3 ply Specimens (Lee, 2013)

Fig. 11 Flexural Stiffness-Number of Strengthening Layers Relationship of 0.60-1 ply, 0.60-2 ply, and 0.60-3 ply Specimens

5. CONCLUSION

In this paper, we present the results of investigation pertaining to the flexural behavior of flange strengthened I-shape pultruded fiber reinforced polymeric plastic member with carbon fiber sheet. From the test, flexural stiffness of flange strengthened I-Shaped PFRP member with 1 layer carbon fiber sheet is 13.15% higher than that of I-Shape PFRP member without flange strengthening. Furthermore, to investigate the flexural strengthening effect depending on the strengthening ply, the number of carbon fiber sheet layer, flexural test on 3 different types with different number of CFRP sheet layer was also conducted. Flexural stiffness and flexural strength of 2 ply strengthened test specimen with carbon fiber sheet was much higher than that of 1 ply strengthened one. On the other hand, flexural strengthening effect of 3 ply strengthened test specimen was less than that of 2 ply strengthened one. Poor adhesion between carbon fiber layers is suspected to be the main reason of flexural stiffness reduction. Thus, 2 ply strengthened specimen is considered to be the most efficient one.

We reported the results obtained in the experimental study and discussed on the results. Future studies on the case of the tension flange strengthened only, bonding technique, prediction technique by the finite element analysis, etc., is needed. Especially, the effects of bonding techniques considering the field conditions may need to be thoroughly investigated to make the method more reliable.

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