STRUCTURAL BEHAVIOR OF PFRP CONNCETION WITH SINGLE BOLT

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Keywords: *PFRP, experiment, lap-joint, bearing stress, failure mode*

1 Introduction

The pultrusion process may be the most popular one in civil engineering applications due to the cost effective productivity. Pultrusion is a continuous manufacturing process for mass production with good mechanical properties. Mechanical properties of the pultruded fiber reinforced polymeric plastic (PFRP) may be considered as an orthotropic material since main reinforcing fibers are aligned with the longitudinal direction of the member [1, 2].

In this paper, we focused on the structural behavior of single bolted lap-joint connections in PFRP structural members. Especially, bolted connections in PFRP plates are investigated for their failure modes and structural behaviors. Dimensions of the specimens have been selected by using recommended geometric parameters for the lap-joint connection in the published documents. Specimens with single bolt-hole have been tested in tension under bolt-loading conditions. The failed specimens were examined for failure load, bearing stress, cracks, and fracture patterns.

2 Previous Research

According to the study conducted by Bank (2006) [3], a review of the extensive research data obtained for pultruded plate materials has led to pertinent geometric parameters for single and multiple bolted lap-joint connections. According to the study conducted by Turvey et al. (2008) [4], three of the principal failure planes: bearing, net-tension, and shear-out are identified graphically in Fig. 1. The fourth failure mode, i.e, cleavage, may be regarded as a combined failure mode involving simultaneous failure along the bearing and net-tension planes. The geometry of a single-bolt joint under tension was defined in terms of three parameters, i.e, the end distance, E (the distance from the center of the bolt to the end of the plate), the width of the plate, W, the bolt diameter, D, and two parameter ratios, i.e., E/D and W/D.

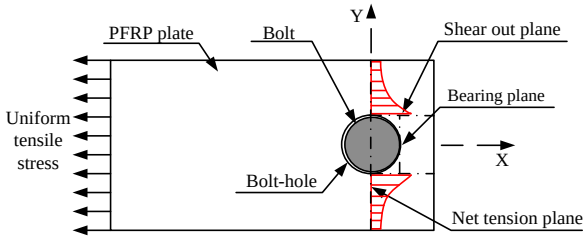
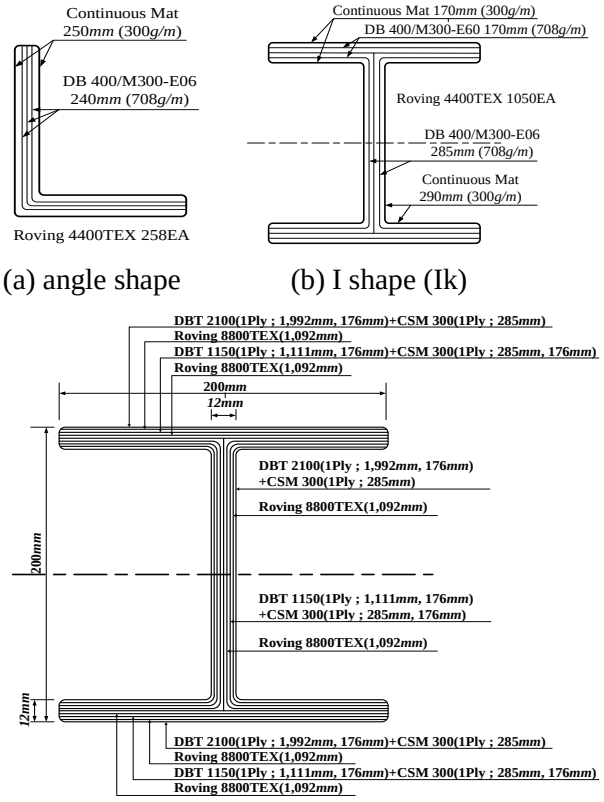


Fig. 1. A single-bolt tension joint showing the principal planes where material failure is assumed to occur in design

3 Mechanical Properties of PFRP Specimen

Tension tests [5] on the PFRP specimens taken along the fiber direction and compression tests on the PFRP specimens taken along the transverse direction are conducted before the testing of PFRP plate connected with bolt at the Structures Laboratory at Hongik University in Seoul, Korea. Iosipescu shear tests [6] of PFRP specimens are also conducted at the laboratory of Hankuk Fiber Co., Ltd. in Korea. These tests have been carried out for three types of glass/polyester PFRP structural member (angle shape and two different wide flange shape). Fig. 2 shows the fiber architecture of PFRP members used in the tests. Average test results are summarized in Table 1. In Table 1, f_t is the longitudinal tensile strength, E_l is the modulus of elasticity along the longitudinal direction, f_c is the transverse compressive strength, E_t is the modulus of elasticity along the transverse direction, and τ_{ft} is the

shear strength of PFRP specimen taken along the longitudinal direction of the member. Fig. 3 shows the tension and shear tests.



(a) angle shape (b) I shape (Ik)

(c) I shape (Ih)

Fig. 2. Fiber architecture in PFRP members

Table 1. Mechnical properties of PFRP specimen

Specimen	Angle	I (h)	I (k)
f_t, [MPa]	323.60	274.53	481.38
E_l, [GPa]	27.71	19.26	33.28
f_c, [MPa]	112.10	93.13	161.52
E_t, [GPa]	10.51	11.55	13.65
τ_{ft}, [MPa]	77.55	102.03	97.35

Fig. 3. Tension and shear tests

4 Experiment of Single Bolted Connection

4.1 Test Variables

In the test, the hole size clearance, the ratio of bolt diameter to plate thickness, the distance from the center of bolt diameter to the edge of plate in the loading direction, and the ratio of plate width to bolt diameter are the test variables, and the others are all fixed as Bank's recommended geometric parameter. Table 2 shows Bank's recommended geometric parameter and Table 3 shows the specimen of bolted connection.

A total of 137 bolted connection specimens (i.e., Angle and Ih specimen: five for each variation, Ik specimen: three for each variation) were also prepared and tested. All specimens of each type were mounted on the specially prepared steel plate test jig. In the test, 10mm diameter structural steel bolt with washers was used to connect the PFRP plates each other [7]. Fig. 4 shows the experiment of bolted connection.

Table 2. Bank's recommended geometric parameter

	Research data		Manufacturer	
	Recommend	Minimum	Recommend	Minimum
e/d_b	≥ 3	2	≥ 3	2
w/d_b	≥ 5	3	≥ 4	3
$d_b/\ t_{pl}$	≥ 1	0.5	2	1
d_h-d_b	Tight fit ($0.05d_b$)	1/16$in.$	1/16$in.$	NA

NA : Not available

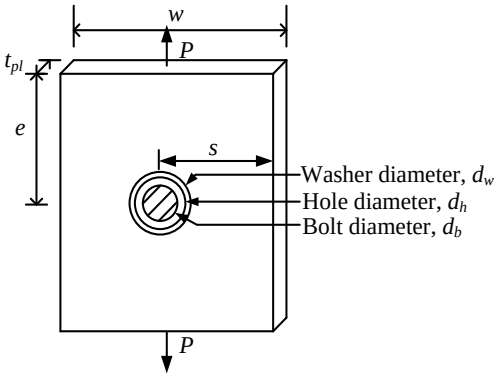


Table 2. Specimen dimension of PFRP bolted connection

Specimen disignation	Dimension (*mm*)					[e/d_b, w/d_b, d_b/t_{pl}, d_h-d_b]
	e	w	t_{pl}	d_b	d_h	
A-E20	20	50	9.5	10	12	[2, 5, 1.05, 2]
A-E30	30					[3, 5, 1.05, 2]
A-E40	40					[4, 5, 1.05, 2]
A-E50	50					[5, 5, 1.05, 2]
A-E60	60					[6, 5, 1.05, 2]
A-E70	70					[7, 5, 1.05, 2]
Ih-E20	20	50	12	10	12	[2, 5, 0.83, 2]
Ih-E30	30					[3, 5, 0.83, 2]
Ih-E40	40					[4, 5, 0.83, 2]
Ih-E50-W30	50	30				[5, 3, 0.83, 2]
Ih-E50-W40		40				[5, 4, 0.83, 2]
Ih-E50-W50		50				[5, 5, 0.83, 2]
Ih-E50-W60		60				[5, 6, 0.83, 2]
Ih-E50-W70		70				[5, 7, 0.83, 2]
Ih-E60	60	50				[6, 5, 0.83, 2]
Ih-E70	70					[7, 5, 0.83, 2]
Ik-E20	20	50	10	10	12	[2, 5, 1, 2]
Ik-E30	30					[3, 5, 1, 2]
Ik-E40	40					[4, 5, 1, 2]
Ik-E50-W30	50	30				[5, 3, 1, 2]
Ik-E50-W40		40				[5, 4, 1, 2]
Ik-E50-W50		50				[5, 5, 1, 2]
Ik-E50-W60		60				[5, 6, 1, 2]
Ik-E50-W70		70				[5, 7, 1, 2]
Ik-E60	60	50				[6, 5, 1, 2]
Ik-E70	70					[7, 5, 1, 2]
Ik-C10	50	50	10	10	10	[5, 5, 1, 0]
Ik-C11					11	[5, 5, 1, 0]
Ik-C12					12	[5, 5, 1, 1]
Ik-C13					13	[5, 5, 1, 2]
Ik-C14					14	[5, 5, 1, 3]
Ik-B8-C1				8	9	[6.25,6.25,0.8, 1]
Ik-B8-C2					10	[6.25,6.25,0.8, 2]
Ik-B12-C1				12	13	[4.17,4.17,1.2, 1]
Ik-B12-C2					14	[4.17,4.17,1.2, 2]

Fig. 4. Experiment of bolted connection

4.2 Test Result

For the effect of the hole size clearance (refer to Fig. 5, Ik-C10~C14), no significant trend on the bearing stress is observed. For constructability, bolt holes are generally oversized by 2*mm* (1/16*in* approximately) in the bolted connection of steel members.

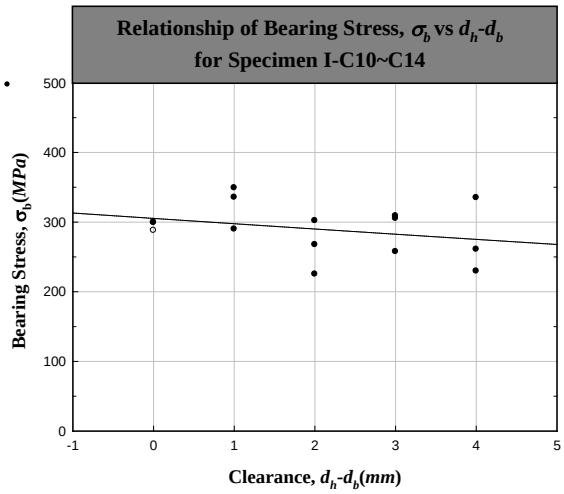


Fig. 5. Relationship of bearing stress vs. bolt clearance

Experimental results suggested that the hole size clearance, 2*mm*, may be adequate. For the effect of the ratio of bolt diameter to plate thickness (refer to

Fig. 6, Ik-B8-C1~Ik-B12-C2, Ik-C1~C2), no significant trend on the bearing stress is also found. Therefore, the ratio of 1 may be suitable as given in the previous research [3].

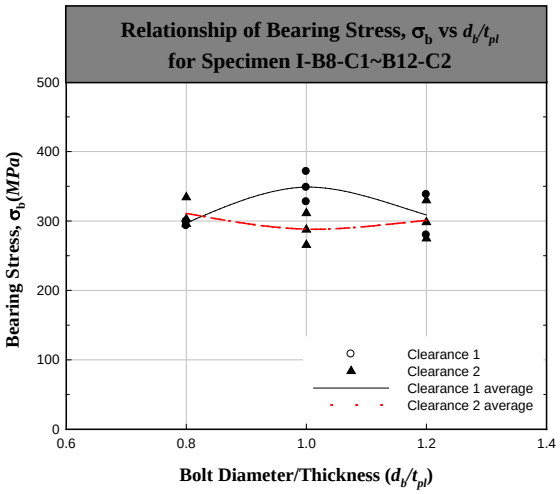
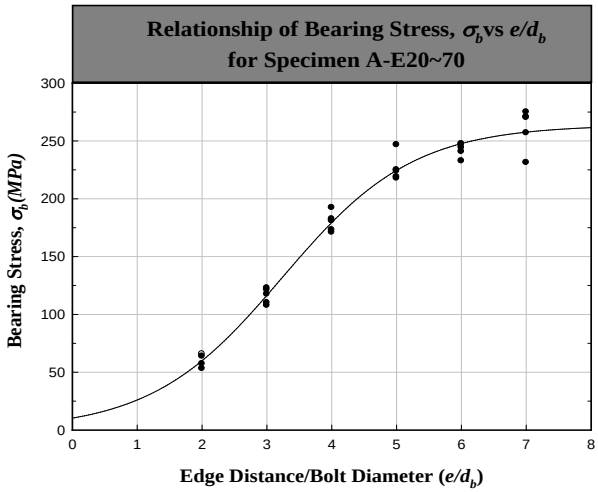
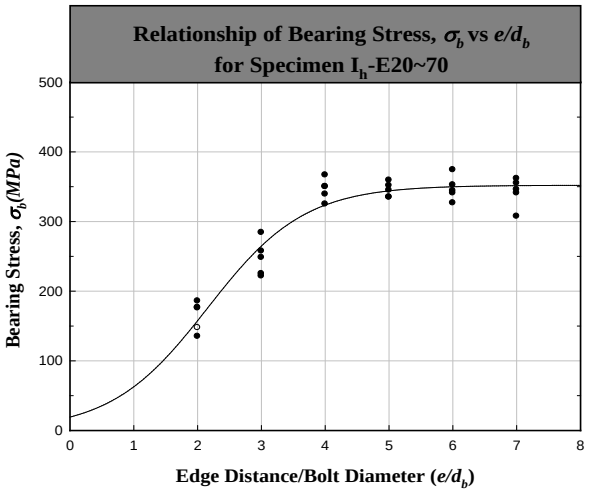


Fig. 6. Relationship of bearing stress vs. plate thickness

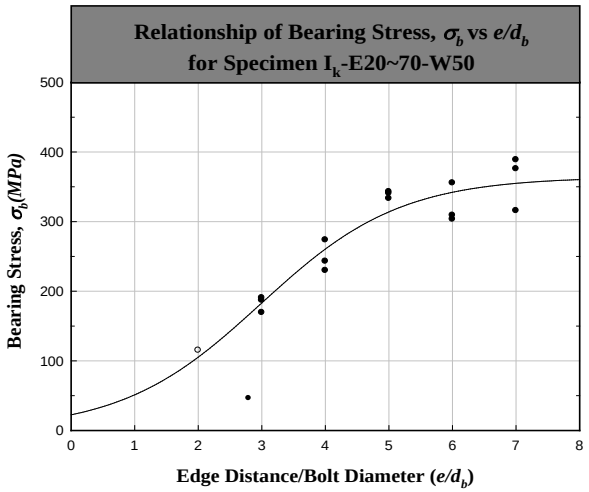
For the effect of the distance from the center of bolt diameter to the edge of plate in the loading direction (refer to Fig. 7, L-20~70, Ih-E20~E70, Ik-E20-W50~E70-W50), bearing stress in the specimens was increased remarkably when the value is 5. When the value is over 5, no significant increase is observed.



(a) A-E20~70



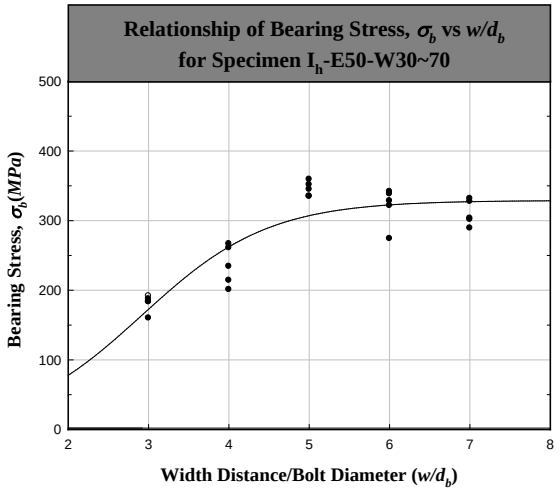
(b) Ih-E20~70



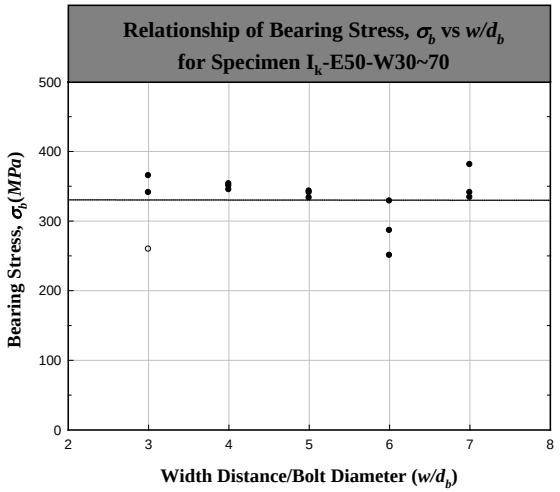
(c) Ik-E20~70

Fig. 7. Relationship of bearing stress vs. edge distance

For the ratio of plate width to bolt diameter (refer to Fig.8., Ih-E50-W30 ~ W70, Ik-E50-W30 ~ W70), when the value is in the range of 3 to 5, the value is increased remarkably. However, the value is over 5, no increase in the value is observed.



(a) Ih-E50-W30~70



(b) Ik-E50-W30~70

Fig. 8. Relationship of bearing stress vs. width distance

5 Conclusions

The effect of the hole size clearance is negligible if the hole size clearance of 2*mm* is used. The effect of the bolt diameter to plate thickness is negligible for the bearing stress. For the effect of the distance from the center of bolt diameter to the edge of plate in the loading direction and the effect of the plate width to bolt diameter, if the ratios are over 5, there is no significant increase. Hence, the ratio of 5 may be appropriate for the design of connection of PFRP members.

Acknowledgment

This research was supported by the grant (code F20833209H140000110) funded by Ministry of Maritime Affairs and Fisheries of Korean government & the Construction Technology Innovation Program (CTIP) of Korea Institute of Construction. The financial support provided by the above institutions is acknowledged.

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