EFFECTS OF THE LAMINATIONS OF GLASS FIBER SHEETS ON THE STRENGTHENING OF PULTRUDED GFRP BOLTED CONNECTIONS

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1. INTRODUCTION

Pultruded glass fiber reinforced polymer (PGFRP) profiles have been used in many fields of structural engineering and infrastructure applications because they offer many outstanding characteristics such as low density, high weight ratio and strength, high corrosion resistance, low heat transmission, and a wide variety of shapes. The popular applications of PGFRP can be found in the construction of bridges, housing, and office buildings. However, the PGFRP profiles, which containing main glass roving parts, usually lack shear strength because the shear strength of the PGFRP profiles is mainly dependent on the matrix shear strength. In this study, the effects of lamination of glass fiber sheets (GFSs) on the strengthening of PGFRP connections were experimentally investigated.

2. SPECIMEN PREPARATIONS

The original PGFRP profiles, as shown in Fig. 1, were used for making the specimens. PGFRP profiles contain two parts: inside unidirectional glass roving (UD) and outside glass fiber mat (GFM). The average thickness of PGFRP channels is 6.5 mm with a total of 5.5 mm thickness for the UD part and 1 mm thickness for the GFM part. The 80 mm-main parts in the webs of the channels were cut for making the specimens of the tensile tests. The original glass fiber sheets for the stacking of different laminations included two types: chopped strand mat (CSM) sheets and 0°–90° woven glass fiber sheets. They are products of Central Glass Co., Ltd., Tokyo, Japan. The 0°–90° woven glass roving fiber sheets can be rotated to create ±45° GFSs. Table 1 shows all the specimens for the tests. In the table, NS means the non-strengthened specimens, the notations from A to I show the strengthened specimens with different types of strengthening GFSs. There are nine types of laminations. CSM means the chopped strand mat GFS (multiple directions), ±45° is the GFSs in the ±45° directions, and 0°–90° means the GFS in the 0° and 90° directions. After arranging the directions and stacking the different fiber sheets, the different laminations of GFSs were fabricated by the Vacuum-assisted Transfer Molding Method (VaRTM). These GFSs were then stuck on both sides of PGFRP plates by E250 high strength epoxy to strengthen the GFRP connections. The connections were kept around one week for curing and then drilling was proceed to make the holes.

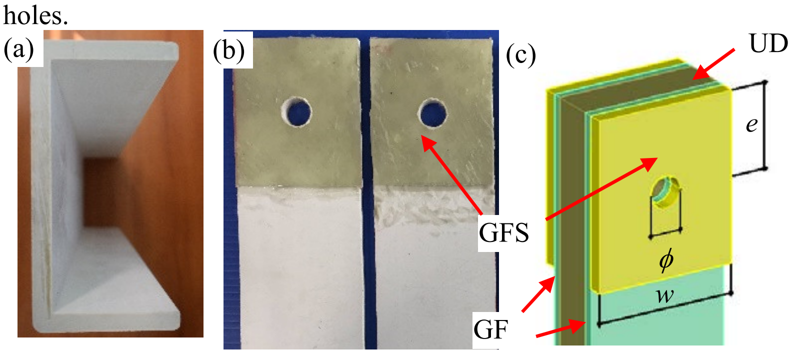

Fig. 1. GFRP connections. (a) original shape, (b) GFRP plates with GFS strengthening, (c) connections configurations.

Table 1. Specimen parameters

Types	Laminations of GFS	Total GFS thickness (mm)
NS	---	---
A	CSM/±45°/CSM	2.62
B	CSM/0°–90°/CSM	2.62
C	$[CSM]_3$	2.76
D	±45°/CSM/±45°	2.48
E	±45°/0°–90°/±45°	2.48
F	$[\pm45°]_3$	2.34
G	$[0°–90°]_3$	2.34
H	0°–90°/CSM/0°–90°	2.48
I	0°–90°/±45°/0°–90°	2.48

3. EXPERIMENTAL PROGRAM

The bearing tests of the PGFRP connections were carried out using a 1000 kN Maekawa tensile testing machine (Maekawa Testing Machine MFG Co., Ltd., Tokyo, Japan), as shown in Fig. 2. Pin-bearing single bolted connections were used for the tests with M16 bolt (d=16mm bolt diameter) and 4d end distance from the bolt-holes to the edges of the specimens (e=64mm). The bolt-holes diameters were 18 mm with 2 mm clearances. The 80 mm widths were set for all the specimens (w=80mm). There was a total of 40 specimens with 4 specimens for each parameter. Two displacement transducers were installed on both sides of the specimens to measure the relative displacements of the specimens.

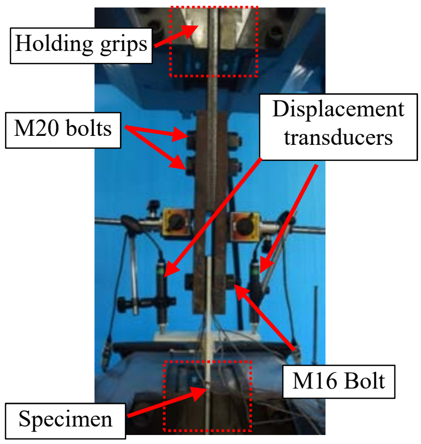

Fig. 2. Experimental setup

4. EXPERIMENTAL RESULTS

Fig. 3 shows different types of failure modes of all specimens in the PGFRP connections and Fig. 4 shows the typical experimental failure modes. The experimental failure modes are shown in the front view and top side view of the specimen. There were generally three types of failure modes. Mode 1 was a shear-out failure in all the thicknesses of the connections in non-strengthened specimens (NS specimens). Mode 2 was a combination of shear-out and bearing failure,

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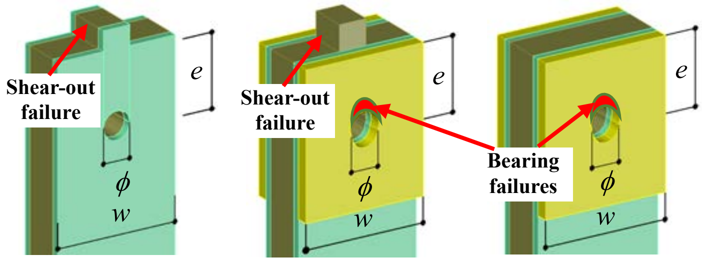
where the shear-out failure occurred in the UD part, and bearing failure took place in the GFM and GFS parts. Mode 3 was a bearing failure in all the thicknesses of the connections. Table 2 shows the different types of failure modes of all specimens. Mode 1 occurred in all NS specimens. Mode 2 took place in types B, C, and F specimens. Modes 3 were found in type G and I specimens. Finally, different failure modes were found in the same GFS strengthening parameter with types A, D, E, and H specimens.



(a) Mode 1 (b) Mode 2 (c) Mode 3

Fig. 3. Three types of failure modes

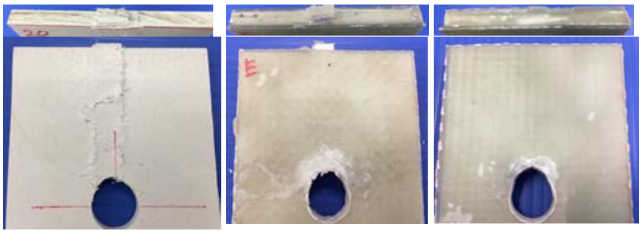

(a) Mode 1 (b) Mode 2 (c) Mode 3

Fig. 4. Typical experimental failure modes

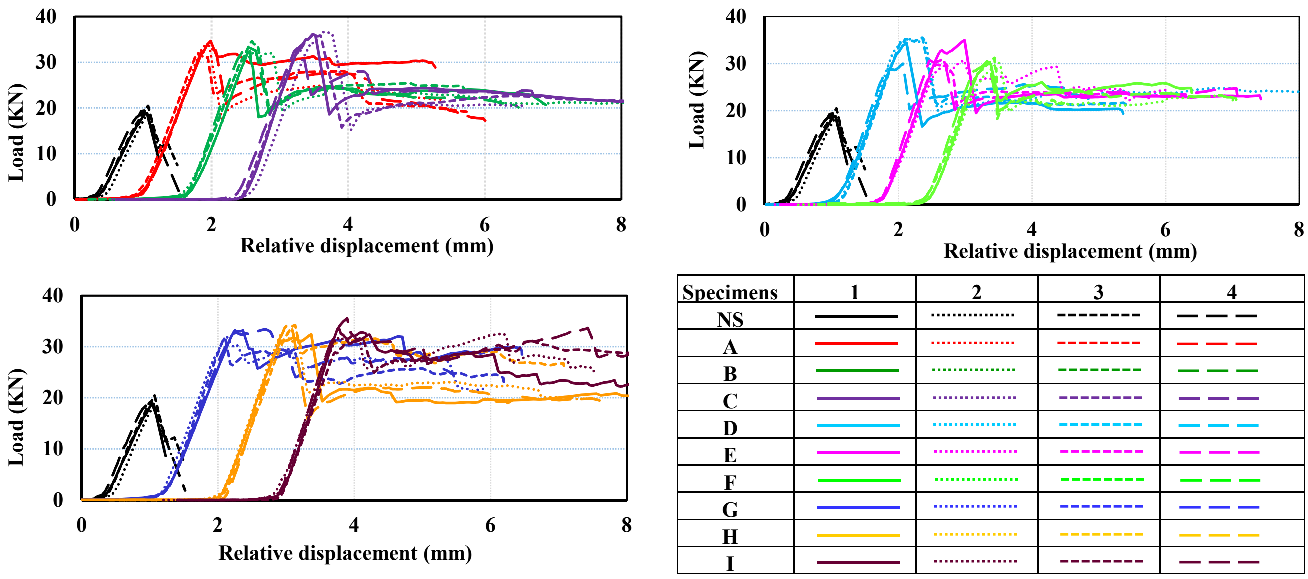


Fig. 5. Load - relative displacement relations of all specimens

Table 2. Strengthening effects of GFSs for the PGFRP connections and experimental failure modes

Parameters	Specimen No.	NS	A	B	C	D	E	F	G	H	I
Load (kN)	1	18.82	34.65	32.35	36.14	34.42	34.99	30.50	33.20	32.42	33.42
	2	18.24	33.75	32.10	36.64	35.24	30.73	30.16	32.12	33.11	32.53
	3	20.45	31.92	34.56	35.99	35.50	30.32	31.24	31.61	34.23	31.99
	4	19.41	32.96	33.35	33.09	29.98	31.33	30.12	33.39	34.49	35.54
Average load (kN)		19.23	33.32	33.09	35.46	33.79	31.84	30.50	32.58	33.56	33.37
C.O.V.		0.04	0.03	0.03	0.04	0.07	0.06	0.01	0.02	0.02	0.04
Strengthening effect (%)		---	73.3%	72.1%	84.4%	75.7%	65.6%	58.6%	69.4%	74.5%	73.5%
				Mode 1 failure			Mode 2 failure			Mode 3 failure	

Fig. 5 shows the load and relative displacement relations obtained from the tests. Table 2 shows the effects of different types of GFS laminations on the strengthening of PGFRP connections. The maximum strengthening effects were found in type C strengthening with 3 layers of GFSs on each side of the connections (84.4%). Type F specimens brought the lowest strengthening effects (58.6%). Although there are no many differences in strengthening effects when using different GFS laminations, types G and I GFSs proved the good laminations for the strengthening when the failure modes changed from all shear-out failures with NS specimens to all bearing failures in strengthened specimens. This is better for the ductility performances of the connections.

5. CONCLUSIONS

In this study, the strengthening effects of different laminations of GFSs on the bearing strengths of PGFRP connections. Four times the bolt diameter was chosen for the end distances. The results show that all types of GFSs could bring higher bearing loads for the connections. However, the use of 0°–90° GFSs or the combination of 0°–90°/±45°/0°–90° GFSs could provide good improvements in the connection ductility because all bearing failures occurred in these types of strengthening specimens.

REFERENCES

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