INVESTIGATION ON EFECT OF GLASS FIBER SHEETS ON THE STRENGTHENGING OF PULTRUDED GFRP MULTI-BOLTED CONNECTIONS

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1. INTRODUCTION

Pultruded glass fiber reinforced polymers (PGFRPs) have been labelled as a material with high strength, stiffness -to-weight ratios, ease of installation, high corrosion resistance, high durability, and high tailorable for constructions. Among many existing issues in design criteria for PGFRP, design of bolted connection is considered as one of the most important aspect. Thin multiaxial glass sheets (GFSs) can be combined with epoxy to create thin sheets that can be used for strengthening of PGFRP connection. This study aims to the investigation of the effects of different types of GFSs for the strengthening of multi-bolt PGFRP connections.

2. SPECIMEN PREPARATION AND EXPERIMENTAL SETUP

The original PGFRP is 5 mm thickness sheets, namely FS1005 (products of Fukui Fibertech Co Ltd., Japan) were used for making the specimens. The FS1005 is included a 1mm thickness continuous chopped strand mat (CCSM), a 4mm thickness unidirectional glass roving (UD.

Three types of GFSs, [0/90], [±45], and [CSM], were used to strengthen the PGFRP connections. Each type of GFS includes 3 layers of laminae. [0/90] and [CSM] laminations were made from 0°/90° woven roving (ERW580-554A:580 (g/m^2)) and CSM (ECM450-50: 450 (g/m^2)), products of Central Glass Co., Ltd., Tokyo, Japan. The 0°/90° woven roving was two-directional, and CSM sheet was a multiaxial glass fiber sheet. [±45] laminations were made by the rotations of [0/90] laminations. Based on the fiber orientation, the CSM can be considered as an in-plane isotropic material. The GFSs were molded by VaRTM method and were bonded to the PGFRP surfaces by the E250 adhesive (product of Konishi, Osaka, Japan). E250 adhesive has the elastic modulus and Possion's ratio of 3 GPa and 0.37, respectively (from the manufacturer).

Table 1. Test program for PGFRP connections

Specimens	*GFS type*	*GFS thickness* [mm]	*No. of specimens*
2A2	[±45]	1.22	3
2B2	[0/90]	1.25	3
2C2	[CSM]	1.55	3
2D2	Non-Strengthening (NS)	0	3

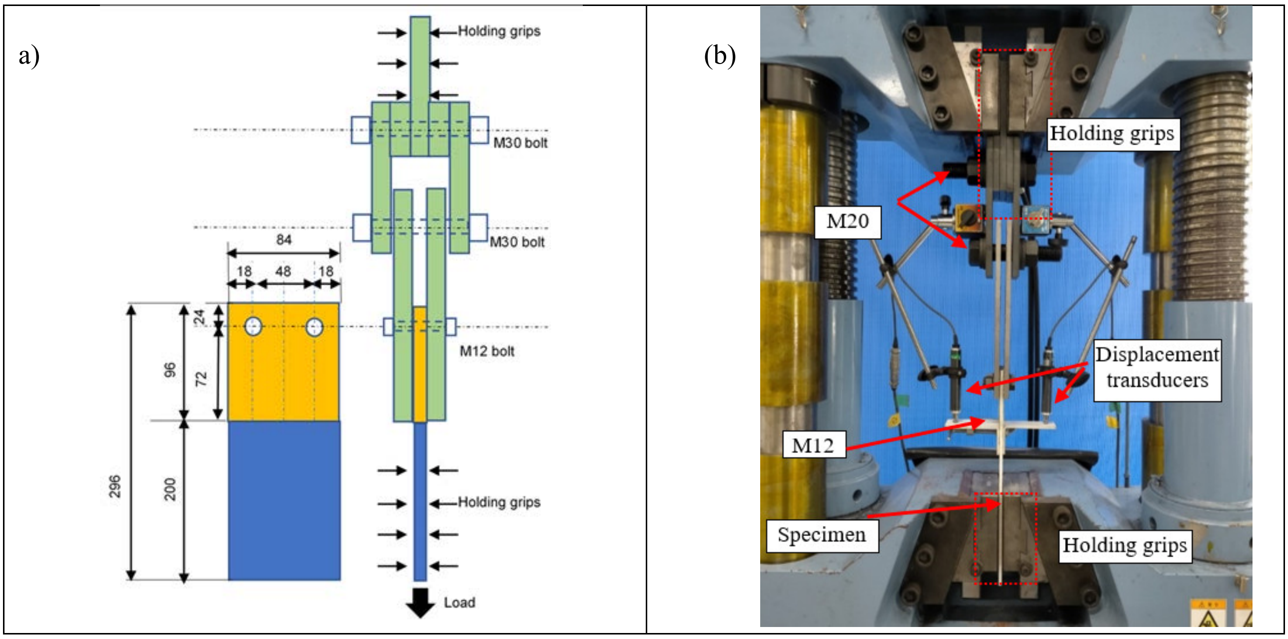

Fig. 1. (a) Specimens configuration and (b) test setup in tensile tests. Unit (mm)

Table 1 shows all the specimens for the tests. Fig.1 shows the test program for PGFRP connection. Two M12 steel-bolts were used for fix specimen with 2 steel-plates according to provisions of ASCE Standards. The bolts should be torquedto the snug-tightened condition. The tightening torque is considered as die-cast plastic applicable product. The value of tightening force 21 (N.mm) was applied for the M12 bolts, which is referred from ISO 6789/2017. The clearance between the bolt shank and bolt hole is maximum of 2 mm.

Keywords: PGFRP, glass fiber sheets, connections, strength,
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The end distance *e* (distance from the center line of bolt hole to the nearest of unload edge that has a plane parallel to the centerline of the bolt row) was chosen equal to two times of bolt diameters (e=2d).

3. EXPERIMENTAL RESULTS

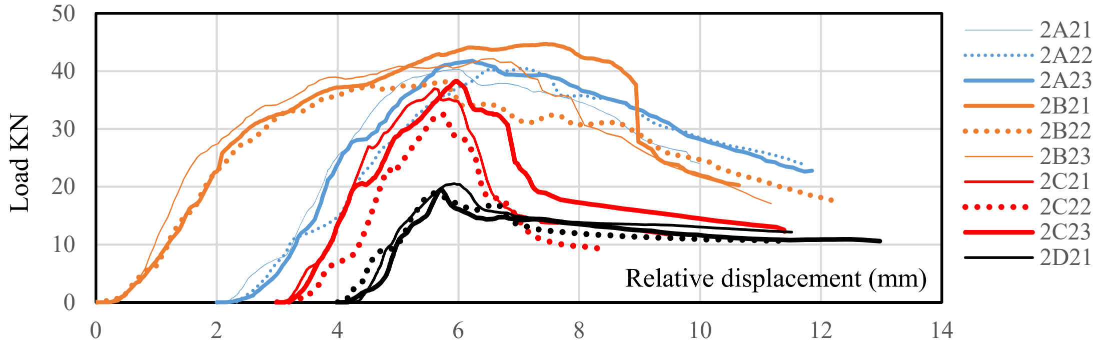


Fig. 2. Load – relative displacement relations

Fig. 2 shows the relations between the loads and relative displacements of all specimens in the PGFRP connections. The values of relative displacements were the average values obtained from two displacement transducers.

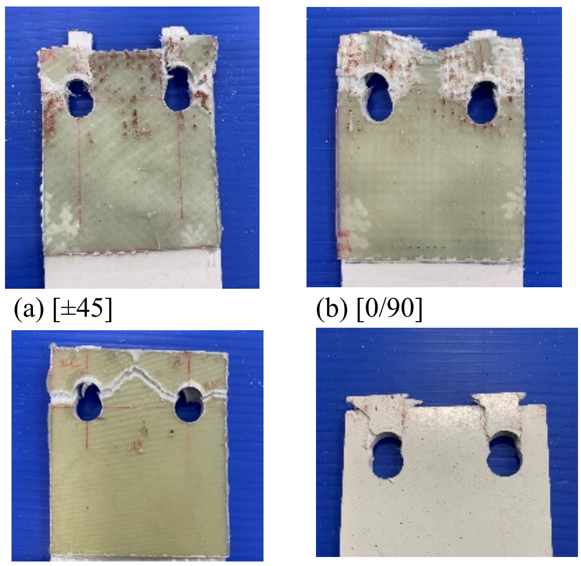
Table 2. The ultimate loads and strengthening effects of GFS for PGFRP

Specim -ens	Type of GFS	Average Max.load (kN)	Coefficient of variation	Strengthening effect (%)	Stiffness (kN/mm)	Stiffness-increased ratios
2A2	[±45]	**40.875**	0.016	107.6%	**20.24**	5%
2B2	[0/90]	**41.683**	0.064	111.7%	**19.3**	0%
2C2	[CSM]	**35.935**	0.067	82.5%	**19.94**	3%
2D2	NS	**19.689**	0.035		**19.3**	

The increases in stiffness of the connection with/without strengthening by GFSs also were shown in Fig. 2. The stiffness calculated from 0.2 $P_{e\text{-}max}$ to 0.5 $P_{e\text{-}max}$ (with $P_{e\text{-}max}$ are the maximum loads in the experiment). The results show that the stiffness-increased ratios of the connections were slightly increase after being strengthened with GFSs.

Tables 2 shows the ultimate loads and strengthening effects obtained from experiments. The ultimate loads of the connections significantly increased after strengthening them with GFSs. After being strengthened by GFSs, the average ultimate loads increased various from 82.5% to 111.7% compared with non-strengthening specimens. The maximum strengthening effect was found in 2B2 specimens with [0/90] GFS, whereas the minimum strengthening effect was appeared in 2C2 specimens with [CSM] strengthening GFSs. All types of GFSs prove their remarkable strengthening effect for PGFRP connection.

Fig. 3 shows typical types of failure modes of all specimens in the PGFRP connections obtained from the experiments. There were generally three failure modes in the connections. Mode 1 was the shear-out failure in the whole thicknesses. This mode can be found in non-strengthened specimens. Mode 2 was the combination between net-tension failures in GFSs and shear out failures in the glass roving parts of PGFRP plates. Mode 2 took place in the specimens strengthened by [CSM] GFSs. Mode 3 was occurred in [0/90] and [±45] GFS-strengthened specimens with the combination of cleavage failures in GFSs and shear out failures in glass roving parts of PGFRP plates.



(a) [±45] (b) [0/90] (c) [CSM] (d)Non-Strengthening

Fig. 3 Failure modes of the PGFRP connections

4. CONCLUSIONS

In this study, the effects of GFSs for the strengthening of multi-bolt PGFRP connections were investigated. One row of bolts with two bolts was selected for the connections. The results showed that GFSs can effectively increase the maximum loads of the connections. The [0/90] GFSs proved the best strengthening effects of all types of GFSs.

REFERENCES

ASCE: Pre-Standard for Load & Resistance Factor Design (LRFD) of PFRP Structures, 2010;

ISO 6789/2017: Assembly tools for screws and nuts — Hand torque tools