Fundamental study on Joint Strength of FRP plates using FRP bolt and Adhesive

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1. Introduction

Pultruded FRPs have been increasingly used in civil infrastructure applications due to advanced properties such as high specific strength, lightweight and especially high corrosion resistance. In highly corrosive environment such as chemical and acid environment where metallic by-products are prone to corrosion, FRP bolts combining with adhesive bonding proved to be an effective solution to increase the durability as well as serviceability of joints in FRP structures. The use of adhesive bonding in addition to FRP bolts not only decreases the structure's weight and limits the impacts of aggressive environment but also increases the ultimate strength of the joint and improve the joint stiffness. However, this kind of connection is quite new and needs more investigations to comprehend clearly the mechanical behaviors of this connection. In this paper, the tension tests with pultruded FRP double-lapped specimens connected by FRP bolts and adhesive were carried out to investigate mechanical characteristics as well as ultimate strength and failure modes of specimens.

2. Experimental method

In this study, the adopted pultruded GFRP plates consisted of continuous strand mats roving and UP (AGC Matex C100B are used). The mechanical characteristics of FRP materials are shown in Table 1. M16 FRP bolts used are made from long glass fiber and thermosetting resin. The mechanical characteristics of FRP bolts are described in Table 2. The bolt head's thickness is 18mm, the length is 60 mm, and one set of specimen uses two 2 mm-thick washers and one 3 mm-thick spring washer. The plate had the dimension L/W/t= 400/80/6.5 (mm) in which 6.5mm is the average thickness of FPR plates, the diameter of the holes in plates is 18 mm. Two kinds of adhesive using in experimental tests are high strength adhesive, Konishi E250 and low elastic adhesive, Konishi MOS8.

Table 1. Mechanical properties of FRP Materials

Properties	Value	Evaluation method
Elastic Module E_x	30 kN/mm^2	JIS K7165
Tensile strength	446 N/mm^2	JIS K7165
Glass Content	38.86 vol%	JIS K7052

Table 2. Mechanical properties of FRP Bolts

M16 Bolt's Load Capacity	Tension Fracture Load (kN)	Shear (kN)	Torque (N.m)
Value	23.5	24.5	73.5

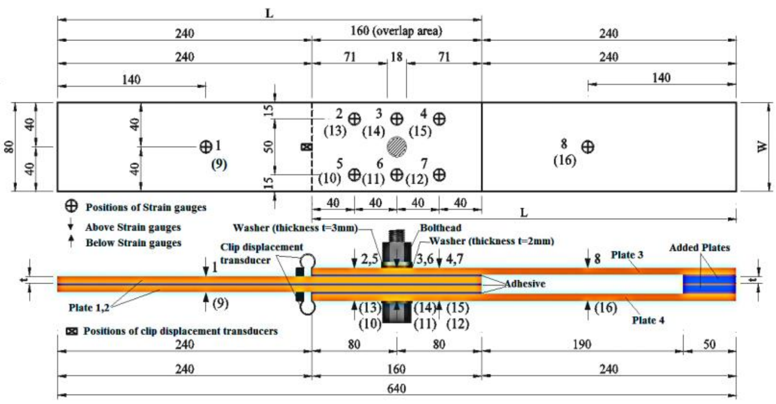

Fig 2. Experimental method and Specimen's dimensions

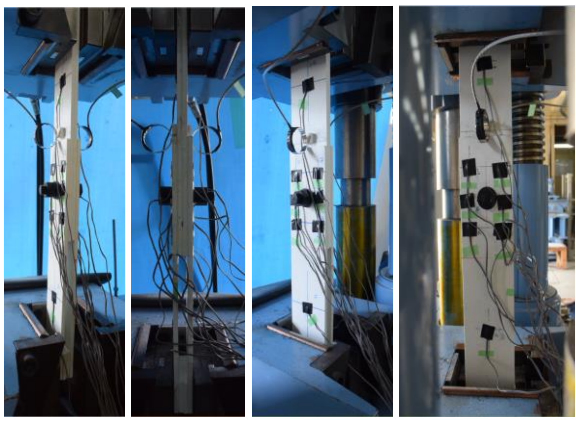

Fig 3. Experimental setup

Six sets, each set includes four FRP plates and two added plates for fixing. Three sets using the same adhesive with E250 or MOS8 were conducted with the same conditions. After creating holes in FRP plates, the surfaces were treated, and these specimens were assembled by adhesive and FRP bolts. The tightening torque of the bolt head was controlled at around 36.7 N.m (50% torque capacity). The tests were performed by using a universal testing machine as Fig 3. Two clip displacement transducers were used on both sides at the end of the cover plate to determine the relative displacement of the cover plate to the main plate as shown in Fig 2.

3. Experimental results and discussions

In the experiments, three sets connected by FRP bolt and high strength adhesive E250 were notated from E250-01 to E250-03, three remained sets with low elastic adhesive were noted from MOS8-04 to MOS8-06. The main failure modes in E250

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adhesive specimens are delamination failure and shear out failure as shown in Fig 4. In these specimens, E250 adhesive was not totally failed, and the failure mainly occurred between laminates of the FRP plates. In contrast, with MOS8 adhesive specimens, the failure occurred at adhesive first and following was shear out failure at the GFRP plates.

Fig 4. Failure modes of specimens with E250 and MOS8 adhesive

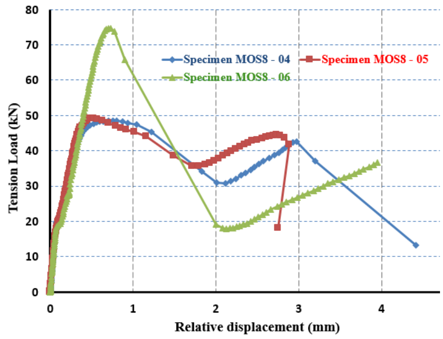

Fig 5. Relative displacement between cover and main plates of MOS8 adhesive specimens

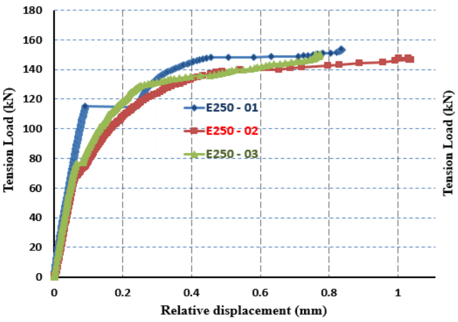

Fig 6. Relative displacement between cover and main plates of E250 adhesive specimens

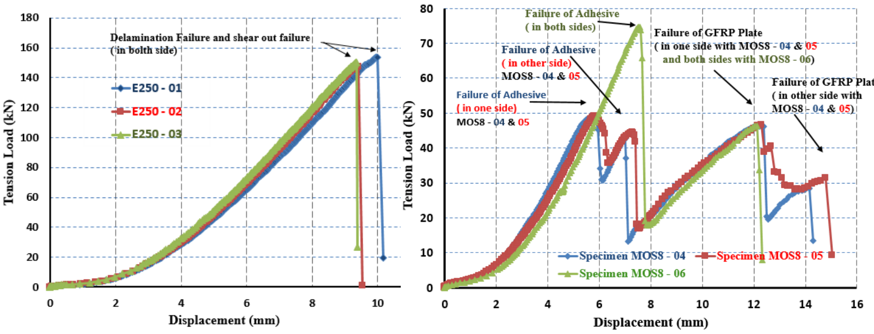

Fig 7. Tension Load – Crosshead displacement relationship

The ultimate strength of connections from the experiments is shown in Table 3. The strength of connections using E250 adhesive is much higher than specimens using MOS8 adhesive. However, the damage of E250 adhesive specimens was sudden at the inner laminates between the GFRP plates. In these cases, E250 adhesive had not yet been damaged. On the other hand, the failure in bonding strength occurred first with MOS8 adhesive specimens and following by shear out failure in FRP plates. With MOS8-04 and MOS8-05 specimens, the failure of bond strength took place alternately on both sides of the connections and then shear out failure occurred alternately on both sides of ones. With MOS8-06 specimen, debonding occurred at the same time on both sides, following by shear out failure at the same time on both sides of the connection. Besides, the relative displacement between cover and main plates of E250 adhesive specimens was lower than that of MOS8 adhesive specimens as shown in Fig 5 and Fig 6.

Table 3: Failure modes and ultimate tension load respectively

S	DF	AF1	AF2	SOF1	SOF2
E250-01	153.85				
E250-02	147.56				
E250-03	150.39				
MOS8-04		48.53	42.52	46.58	28.41
MOS8-05		49.15	44.39	46.55	31.35
MOS8-06		74.76		46.39	

S: Specimen
DF: Delamination failure of GFRP plates
Max P: Max ultimate tension load
AF1 & AF2: Adhesive failure in one side and remained side
SOF1 & SOF2: Shear out failure in one side and remained side

4. Conclusions

Delamination and shear out failure are the main failures of high strength E250 adhesive specimens. Debonding and shear out failure are observed from experiments with MOS8 adhesive ones. The ultimate joint strength of specimens with E250 adhesive bonding is the highest but the failures occur suddenly and this can cause danger when structures are damaged. With MOS8 adhesive specimens, because of the bearing strength did not occur, it is necessary to adjust the diameter of the holes in future research so that the bond strength and bearing strength can work together to increase the joint strength of connections.

Acknowledgements

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