EXPERIMENT ON THE BOLTED JOINT STRENGTH OF PULTRUDED GFRP LAMINATES

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Abstract

This paper aims at investigating the bolted joint strength in GFRP laminates applied to civil infrastructure as structural members. The authors focused on the effects of the stacking sequence, the bolt clamping force and the adhesive types. The experimental results for the hand clamped bolted joint show that the stacking sequence including more bias plies and long edge distance increase the joint strength. Those for the wrench clamped bolted joint also show that the high bolt clamping force and the high strength adhesives increase the joint strength.

1. Introduction

Bolted joints are general joints of structural members in civil structures. It is important to obtain the mechanical properties of bolted joints in FRP laminates, in the case of applying FRP laminates as structural members in civil structures. Bolted joints, rivets and pin joints are generally used in steel structures, which results in the mechanical properties of these joints investigated sufficiently. But, few existed FRP civil structures require more investigation on the joints in FRP laminates as structural members. The authors conducted the experiment on the strengths of large-diameter bolted joints in GFRP laminates, to obtain the effects of stacking sequence, bolt clamping force and adhesive types.

2. Specimen

The GFRP specimens used in this experiment consist of continuous strand mat (CSM), bias, cloth and roving layers. CSM layer consists of continuous strand mat with randomly oriented fibers. Bias layer consists of the ±45° oriented fibers. Cloth layer consists of the 0/90° oriented fibers. Roving layer consists of the 0° oriented fibers. These specimens have sufficient tensile properties as structural members, which results in high volume fraction of roving layer. The glass-fiber is E-glass and the resin is vinyl-ester resin. Type 1 GFRP specimen and type 2 GFRP specimen are used in this experiment. The difference of these 2 types is the number of bias plies. These numbers are 8 for type 1 and 12 for type 2, respectively. The stacking sequences of these GFRP specimens are CSM/Bias/Cloth/Bias/Cloth/Rov/Cloth/Bias/Cloth/Bias/CSM. The fiber volume fraction for each layer and the specimen geometry are shown in Table.1 and Fig.1, respectively. The specimen thickness is 27mm, the length is 250mm, the width is 102mm, the hole diameter is 21mm and the edge distance is 63mm or 84mm.

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Table.1 Fiber volume fraction of GFRP specimen

Type 1		Type 2	
Layer	V_f	Layer	V_f
CSM	1.6%	CSM	1.6%
Bias	9.4%	Bias	12%
Cloth	2.1%	Cloth	2.1%
Roving	39%	Roving	36.4%

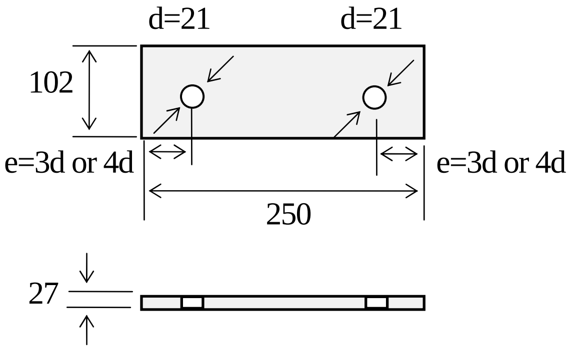

Fig.1 GFRP specimen geometry

3. Experiment

The GFRP specimen is set as shown in Fig.2 to measure the joint strength. The specimen is clamped with the bolt through the 27mm thickness steel plate. The steel plate is SS400. The bolt is M16 (FT10T). Applying the tensile load for the specimen, the load and strain were measured. The strain gages are attached to the both sides of the specimen as Fig.2.

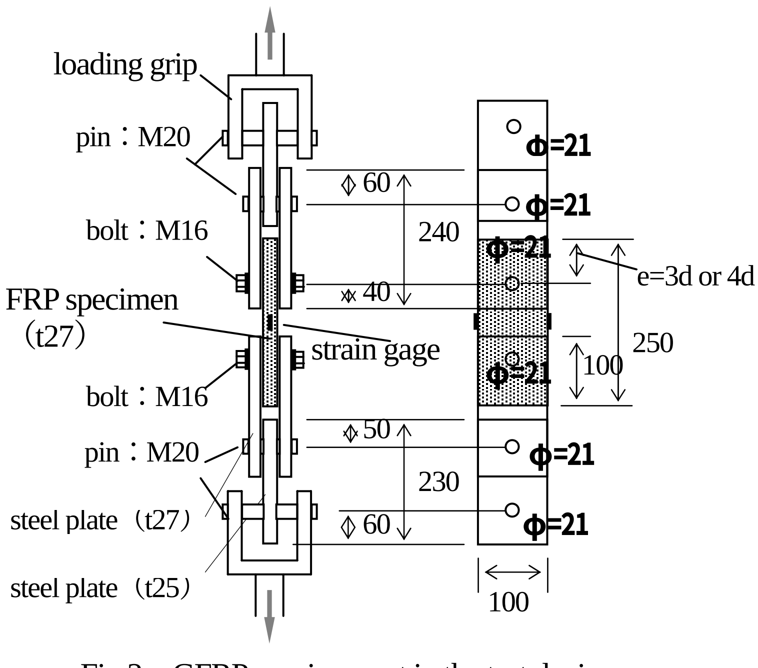

Fig.2 GFRP specimen set in the test device

3.1 Hand Clamped Bolt

In this experiment, the bolt is slightly hand clamped and the edge distance is 3d or 4d (d=21mm). The maximum load and the strain are measured. The maximum loads are shown in Fig.3. The failure mode for the maximum load is considered as the shear-out failure.

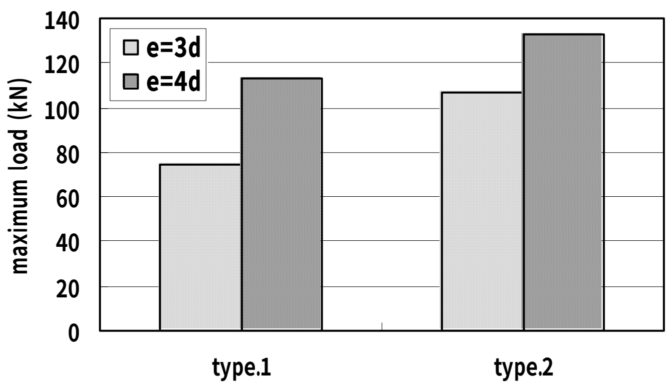

Fig.3 Maximum load for the GFRP specimen

For both 3d and 4d edge distance cases, the maximum loads for type 2 specimen are larger than those for type 1 specimen because more bias plies are used in type 2 specimen. The ±45° oriented fibers in the bias layers have the shear resistance. On the other hand, no fiber in the roving layer and only 90° oriented fibers in the cloth layers have shear resistance. The bias layers have stronger shear resistance than the roving layer and the cloth layers. For both type 1 specimen and type 2 specimen, the maximum loads increase with the edge distance. The maximum load for type 1 specimen with 4d edge distance is almost equivalent to that for type 2 specimen with 3d edge distance. In terms of cost/performance, the joint with the longer edge distance is more cost effective than that with more bias plies.

Fig.4 is the example of the strain against the load for type 1 specimen with 3d edge distance. No.1 and No.2 show the strain gages at the side of the specimen. The strain increases linearly with the load until the maximum load. The load increases again after the load drop, leading to the complete failure consequently. Photo.1 shows the specimen situation after the failure.

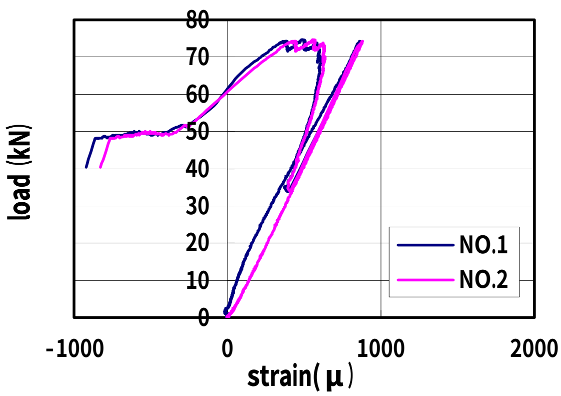

Fig.4 Load-strain curve without clamping force

Photo.1 Specimen situation after the failure (slightly hand clamped bolt)

3.2 Wrench Clamped Bolt

The joints considered in this experiment are the only wrench clamped bolted joint and the combined wrench clamped bolt and adhesive used joints. The adhesive is used between the steel plate and the GFRP specimen. Type 1 specimen is only used as the specimen. The washer is used between the steel plate and the GFRP specimen. The inner diameter of the washer is 17mm and the outer diameter is 31mm. The surfaces of the specimen and the steel plate are left unprocessed for the only wrench clamped bolt case. For the combined wrench clamped bolt and adhesive used cases, the specimen surface is processed with sand-paper.
Two types of the adhesives are used. One is the generally used adhesive, EP-007 by Cemedine co. ltd and the other one is the special adhesive with high strength, Dexter HYSOL, HYSOL EA9309NA. The catalogue data on the mechanical properties of both adhesives are shown in Table 2.

Table.2 Mechanical properties of adhesives

	Tensile Shear Adhesive Strength (MPa)	Elastic Modulus (MPa)
EP-007	22.0	3000～5000
HYSOL	34.5(25℃)	2069(25℃)

Fig.5 shows the maximum loads for various clamping forces in the only wrench clamped bolt and the combined wrench clamped bolt and adhesive used cases. In the experiments, the maximum load for the combined wrench clamped bolt and HYSOL used case is largest. According to the experiments for the 0kN, 57kN, 80kN and 115kN clamping forces, the maximum load increases with the clamping force. The above situation is same among all joint types. Not only the friction force between the specimen and the steel plate but also the lateral constraint of the specimen may increase the joint strength. Furthermore, the adhesive largely increases the joint strength. The relatively large adhesive area may result in the increase of the joint strength. In terms of adhesive types, the strength difference between HYSOL and EP-007 is about 50kN.

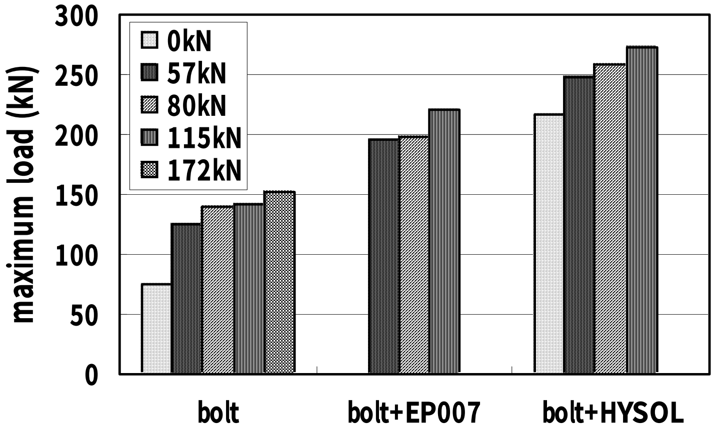

Fig.5　Maximum load with clamping force

Fig.6 shows the load-strain curve for the wrench clamped bolted joint. The curve geometry is similar to the load-strain curve for the hand clamped bolted joint. After the load drop from the maximum load, the load is still at high level. It is probably because the friction force between the specimen and the steel plate still exists. Photo.2 shows the specimen situation after the failure.

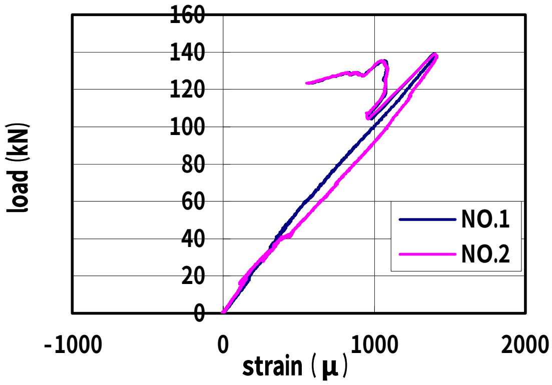

Fig.6　Load-strain curve for the only wrench clamped bolt case (clamping force : 80kN)

Photo.2　Specimen situation after the failure (clamped bolt)

Fig.7 shows the load-strain curve for the wrench clamped bolt and EP-007 adhesive used case. The bolt clamping force is 80kN. According to this figure, the load goes up linearly and then in a zigzag, leading to the maximum load. This situation is also seen for the case with 115kN clamping force. The reason of load drop before the maximum load is that the partial debonding occurs at the adhesive layer. The failure occurs at the adhesive layer. The load after the maximum load gradually decreases. It is partly because the post debonding friction force still exists after the maximum load. Photo.3 shows the specimen situation after the failure.

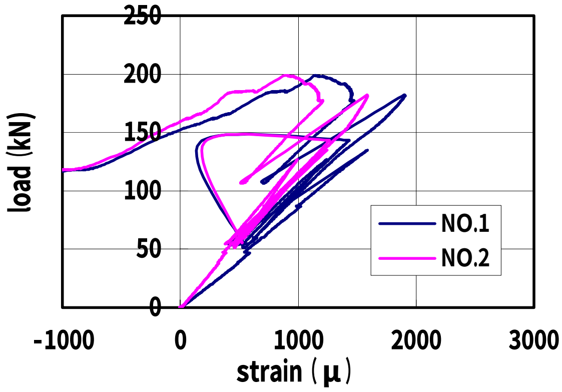

Fig.7 Load-strain curve for the clamped bolt and EP-007 case (clamping force : 80kN)

Photo.3 Specimen situation after the failure (clamped bolt and EP-007)

Fig.8 shows the load-strain curve for the wrench clamped bolt and HYSOL adhesive case. The clamping force is 80kN. In this case, the maximum load is larger than that for the wrench clamped bolt and EP-007 adhesive case. According to this figure, the load goes up linearly and then in a zigzag around the maximum load. After the maximum load, the load decreases rapidly. Photo.4 shows the specimen situation after the failure. According to this photo, the failure occurs at both the adhesive layer and the inner part of the specimen. The failure at the inner part causes less resistance against the load after the failure. It is because the fibers to resist the shear force are fractured and no post debonding friction force exists. The maximum load for the wrench clamped bolt and HYSOL case is larger, but the specimen toughness is lower than that for the wrench clamped bolt and EP-007 adhesive case.

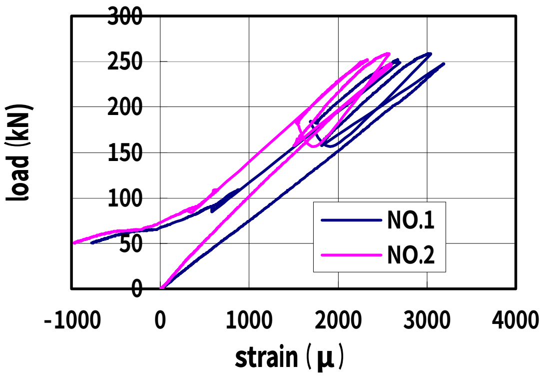

Fig.8 Load-strain curve for the clamped bolt and HYSOL case (clamping force : 80kN)

Photo.4 Specimen situation after the failure (clamped bolt and HYSOL)

4. Conclusions

1) The long edge distance and the bias layers increase the joint strength in the hand clamped bolted joint. In terms of cost/performance, the long edge distance has more cost effective on the increase of the joint strength
2) The joint strength increases with the bolt clamping force in the only wrench clamped bolt case. It is similar to the combined wrench clamped bolt and adhesive used cases. The friction force between the specimen and the steel plate and the lateral constraint of the specimen may contribute to the increase of the joint strength.
3) The joint strength for the wrench clamped bolt and HYSOL case is larger than that for the wrench clamped bolt and EP-007 case. In the HYSOL case, the failure occurs at the inner part of the specimen. It causes the lower specimen toughness than the wrench clamped bolt and EP-007 case.

References

1) Takeshi Kishima and Seishi Meiarashi, The Strength of Large-Diameter Bolted Joints in GFRP Laminates as Structural Members, ICCE/9, 523-524 (2002.7)