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Shear Performance of Glass Fiber Reinforced Glulam Bolted Connection[1]

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ABSTRACT

To evaluate the shear performance of the textile glass fiber and the sheet glass fiber reinforced glulam bolted connections, a tension type shear test was conducted. The average yield shear strength of the bolted connection of reinforced glulam was increased by 12% ∼ 31% compared to the non-reinforced glulam. It was confirmed that the shear performance of 5D end distance of the glass fiber reinforced glulam connection corresponds to that of 7D of the non-reinforced glulam connection proposed in building design requirements in various countries. Compared to the non-reinforced glulam, the average shear strength of textile glass fiber reinforced glulam was markedly increased. The non-reinforced glulam and the GFRP reinforced glulam underwent a momentary splitting fracture. However, the failure mode of textile glass fiber reinforced glulam showed a good ductility.

Keywords : reinforced glulam, glass Fiber, bolted connection, tensile shear test, yield strength

1. INTRODUCTION

To design a timber, a performance evaluation of connection strength is very important. The bolted connection, which is the representative timber connection type using metallic fasteners, has unique characteristics, and these characteristics are reflected in the connection strength. When structural materials are wood-based, splitting fractures occur when a tensile load at a constant end distance is applied, and this characteristic acts as a vulnerability that reduces the strength of the timber structure itself in a timber structure design (Soltis *et al*., 1986; Wilkinson, 1986). Pederson (2002) stated that in the strength model of a dowel-type connection, a tensile stress and a bearing stress occur in the direction of the end distance in timber connection, and an eccentric tensile stress occurs in the direction of the edge distance. As such, if the structural material itself is complemented or reinforced against stresses acting

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Table 1. Properties of glass fiber reinforcements

Reinforcement	Material		Thickness (mm)	Orientation of glass fiber	Tensile strength (MPa)
	Main	Adhesive			
Sheet GFRP	E-Glass Fiber	Epoxy	1.0	Uni-directional	1633
Textile glass fiber		-	Warp : 0.25	Bi-directional	-
			Weft : 0.25		

on the connection, an improvement in the strength not only of the connection but also of the timber structure itself can be expected. Currently, reinforcement methods of structural material are being developed, and studies on means using such steel or aluminum, etc. as reinforcement are actively being pursued in overseas countries (Mark, 1961; Lantos, 1970; Ogawa, 2000; Hernandez *et al*., 1997). In the case of structural glulam, reinforcement of the entire structural members is generally needed for the simplification of the manufacturing process. However, reinforcing the connection is too difficult and generates the waste of the structural member due to setting the reinforcement on connection. It is believed that by reinforcing the connection on the manufacturing process, it would be possible to confirm the structure's strength improvement effects.

By producing sheet GFRP reinforced glulam and textile glass fiber reinforced glulam, for the testing conducted in this paper a reinforcement was inserted into the manufacturing process, and the tensile shear strength performance of the bolted connections was evaluated. The tensile test specimens were produced as a steel plate insertion type. The end distance of bolted connection, which is dependent on the diameter of the bolt (D), was 5D or 7D. In order to verify the reinforcing effects of the reinforced glulam, these were compared with the connection strength of 5D and 7D.

2. MATERIALS and METHODS

2.1. Test Materials and Reinforcements

For the lamina for the production of the glulam, average moisture content of 12% was ensured and domestic larch (*Larix kaempferi* Carr.) with an average specific gravity of 0.6 was used. As the reinforcement, textile glass fiber and sheet GFRP were used. The textile glass fiber was arranged in an overlapping plain with thick fiber bundles in warp and weft configuration (Table 1). In the case of the sheet GFRP, it was formed from a combination of glass fiber and epoxy resin, and unlike the textile glass fiber, was arranged in a longitudinal direction, and the thickness of sheet GFRP was 1 mm (Fig. 1).

2.2. Production of Reinforced Glulam and Steel Plate Insertion Type Shear Specimen

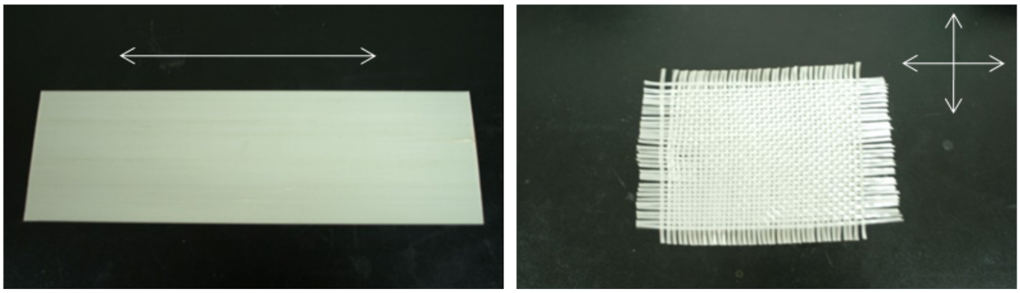
The glulam and reinforced glulam were 5 ply, and the reinforcing material was inserted in

Table 2. Nomenclature of control and reinforced glulam connection specimens

Fastener	Bolt Diameter	Reinforcement	Abbreviation	End-distance
Bolt	12 mm	Non-reinforced	CO	5D*
		Sheet GFRP	GS	
	16 mm	textile glass fiber	GT	7D

* “D” means the diameter of bolt

↔ Orientation of the glass fiber



(a) (b)

Fig. 1. Materials of sheet GFRP (a) and textile glass fiber (b).

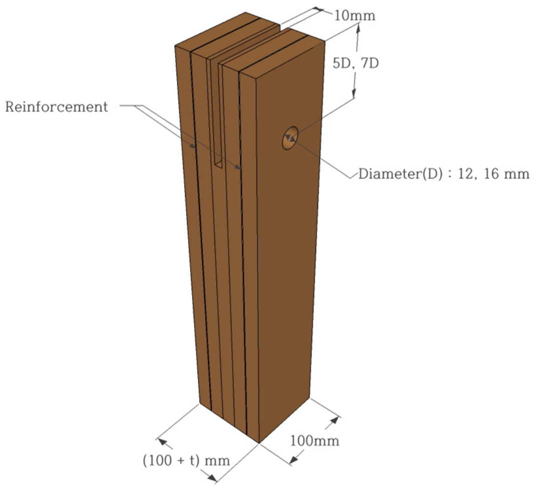


Fig. 2. Connection shape of reinforced glulam specimens.
(Note : “t” in depth is thickness of reinforcement).

between the outermost lamina and inner lamina and plied (Fig. 2). In the case of the sheet GFRP reinforced glulam, a “GS” marking was used, while for the textile glass fiber reinforced glulam, a “GT” marking was used. For the production of the GS glulam, the adhesive used was a vinyl acetate resin type adhesive of MPU500/HH60, while for the GT glulam, a resorcinol resin adhesive of Synteko1711/2623 was used. For the produced glulam, as shown in Fig. 2, in order to produce the steel plate insertion type shear specimen, bolt holes were located at 5D end distance (D = diameter of bolt) and at 7D which is the standard for design standards. In the middle of the glulam, a 10 mm slit was made to accommodate the insertion of a 8 mm steel plate. In accordance with the specimen types, 5 each, i.e., a total of 60 pieces of specimens were produced. The nomenclature of the specimens is presented in Table 2.

2.3. Tensile Shear Testing Method

For the tensile type shear testing, steel plates were inserted into the shear specimen and were connected via 12 mm and 16 mm bolts. Metallic devices were installed on the inserted steel plates, and by attaching 2 displacement transducers (50 mm capacity) on either side, the average values of measurements were used. As a fixture of specimens, two bolts with 20 mm diameter were used, and the bolt spacing and end distance fixture was 60 mm and 130 mm, respectively. Load and deformation were recorded using a data logger (TDS302), and the loading speed was 10 mm/min.

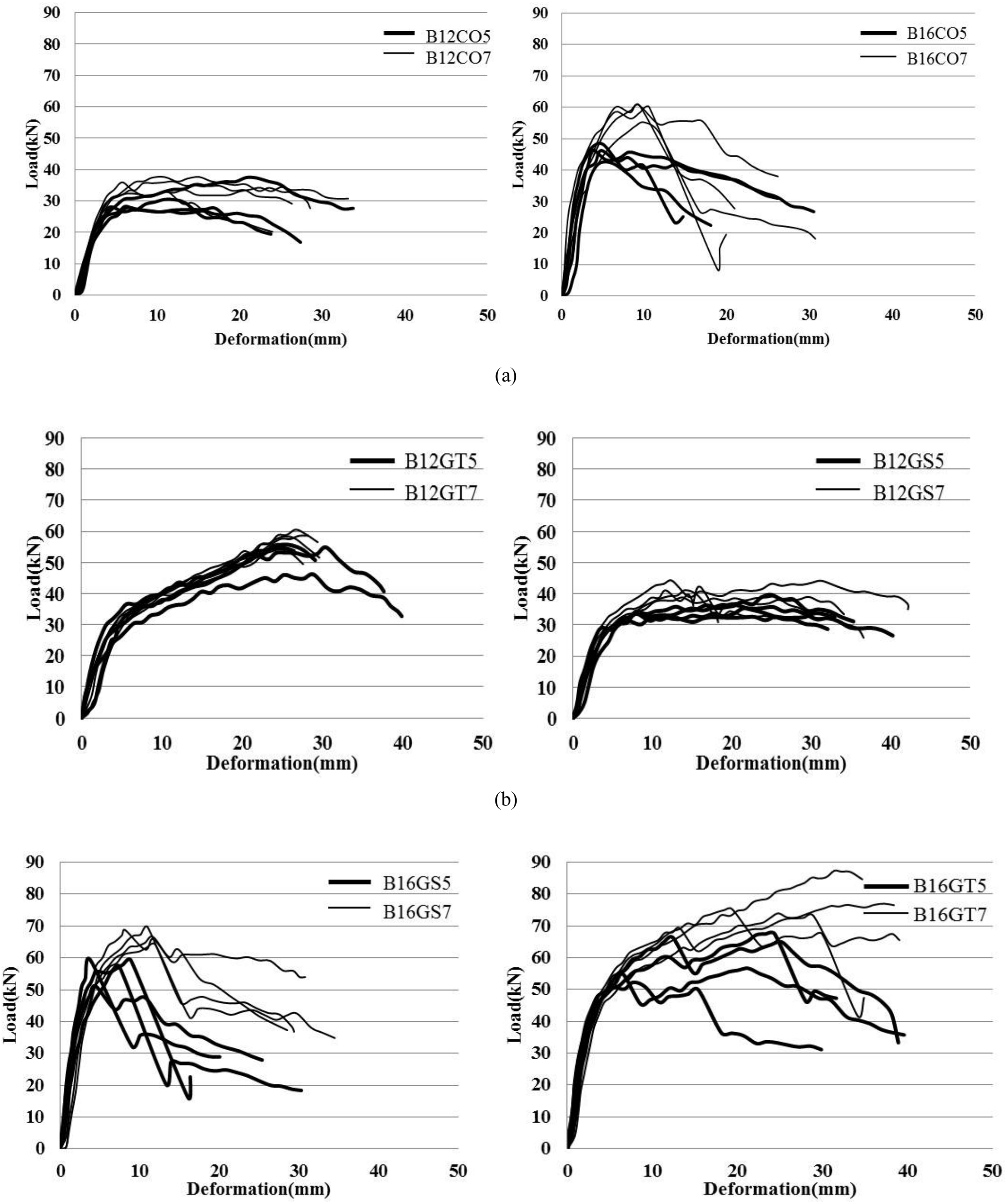
3. RESULTS and DISCUSSION

3.1. Shear Strength of The Bolted Connection of Reinforced Glulam

The average maximum shear strength of the control material of the 7D end distance for the 12 mm diameter bolted connection was 35.44 kN, and in the case in which the end distance was decreased to 5D, the average maximum shear strength was decreased by 13%. The average maximum shear strength of the control specimen of the 7D end distance for the 16 mm diameter bolted connection was 59.12 kN, and for 5D, it was decreased by 23% compared to the average maximum shear strength of 7D. The average maximum shear strength, which is dependent on the increase in the bolt diameter of the same end distance, was increased by 39% in the case of 5D and by 58% in the case of 7D. The load deformation curve of the 12 mm control bolted connection displayed, after reaching the maximum shear strength, a better ductility than the 16 mm.

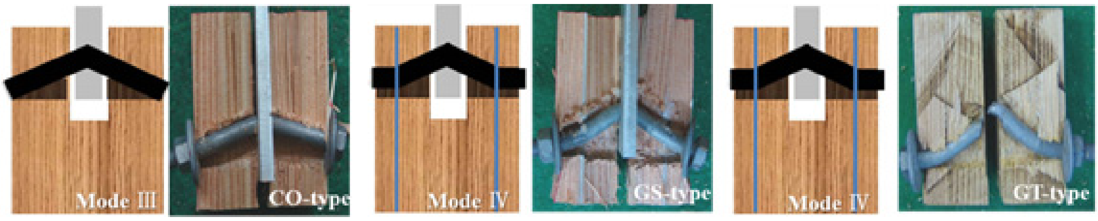
The maximum shear strength of the bolted connection of the 12 mm GS reinforced glulam with 7D end distance was 41.67 kN and it was decreased by 13% in the case in which the end distance was decreased to 5D, and with the maximum strength of Control 7D as the basis, that of 7D of GS specimen was increased by 18%. The 16 mm bolted connection 7D was 67.33 kN, and it displayed a similar rate of decrease as the 12 mm when the end distance was decreased, and with the Control 7D specimen as the basis, it showed values that were increased by 20%. In accordance with the increases in the bolt diameter, the average maximum shear strength of the same end distance showed increases of 54% in the case of 5D, and of 62% in the case of 7D. The load deformation curve of the bolted connection of the GS glulam showed a good ductility after the maximum shear strength at 12 mm, but at 16 mm, it was possible to ascertain that after the maximum shear strength was reached the load decreased momentarily.

For the bolted connection of the 12 mm GT reinforced glulam, the maximum shear strength of the 7D end distance was 57.94 kN, which was similar for the 5D, and most of the maximum load of the GT specimen measured by failure of bolt. With the Control 7D as the basis, the average maximum shear strength of GT glulam increased by 71% and 63% in the cases of 5D and 7D, respectively. Fig. 3 shows

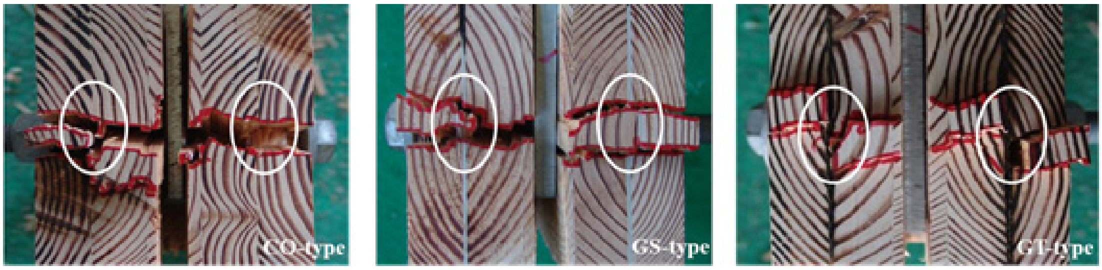


(c)

Fig. 3. Typical load-deformation curves of CO (a), GS (b) and GT (c) specimens using 12 mm (right) and 16 mm (left) bolt according to end distance 5D (bold line) and 7D (ordinary line).



(a)



(b)

Fig. 4. Failure mode by type of specimen (a-inner side, b-upper side).

that the shear strength of the GT specimens using 12 mm bolt displayed a modest stiffness past the proportional limit region until the maximum shear strength, and that as the bolt failed the shear strength decreased slowly, while displaying a good ductility. In the case of the 16 mm, the maximum shear strength of 7D was 78.29 kN, and it showed a decrease of 22% when it was decreased to 5D. The load deformation curve of the 16 mm showed the first phase shear strength, as the timber between the steel plate and the reinforcement broke; however, afterwards, as the reinforcement inhibited the spreading of splitting fracture, it was possible to ascertain that the textile glass fiber and the outermost lamina that were still intact maintained the shear strength.

3.2. Failure Mode of the Bolted Connection of Glass Fiber Reinforced Glulam

The failure behaviors from the current test were compared with the failure modes proposed by the EYM. It is reported that the failure mode of the bolted connection of larch glulam were mostly momentary splitting failures of the glulam (Masahiro *et al*., 2009).

In the cases of the bolted connections of the 12 mm of the control glulam (CO5, CO7) and sheet GFRP reinforced glulam (GS5), the failure phenomenon, as shown in Fig. 4, the center of the bolt bent due to tensile load, thereby embedding the glulam and the reinforced glulam and causing a shear splitting fracture, but the bolt did not fail (Mode Ⅲ). In the case of 7D end distance of the GS and the GT, the failure mode was such that the bolt yielded at the

Table 3. Failure mode and ratio of bolt failure in bolted connection

Diameter of bolt	Type of glulam	Failure mode		Ratio of bolt failure(%)	
		5D	7D	5D	7D
12 mm	CO	Mode Ⅲ	Mode Ⅲ	0	0
	GS	Mode Ⅲ	Mode Ⅳ	0	0
	GT	Mode Ⅳ	Mode Ⅳ	60	80
16 mm	CO	Mode Ⅲ	Mode Ⅲ	0	0
	GS	Mode Ⅲ	Mode Ⅲ	0	0
	GT	Mode Ⅲ	Mode Ⅲ	0	20

center of the bolt and the reinforced position (Mode Ⅳ). Table 3 shows the comparison of the failure mode and ratio of bolt failure by each type, and it indicates that the textile glass fiber reinforced glulam displayed a higher failure ratio of the bolt than the control glulam and the sheet glass fiber reinforced glulam. The failure mode of the bolted connection of the 16 mm manifested, as a result of increases in the diameter, as the Mode Ⅲ, while in the case of the control glulam, the failure mode of momentary splitting was observed. This was a similar trend to the results observed by Kim *et al*. (2008) where, in the performance evaluation of the connection shear strength of a steel plate insertion type drift pin of glulam, Mode IV was transformed into Mode III when the bolt diameter was increased from 6 mm to 12 mm. The failure mode of a single bolted connection shows that as the diameter increases, the plastic yield deformation is reduced, and as the diameter decreases, the failure mode of Mode IV is measured more than Mode Ⅲ. For the failure mode of a multi-row bolted connection, it is reported that failure modes differ with different diameters, like a single bolted connection (Mastschuch, 2000). The GS specimen using 16 mm bolt showed a similar failure behavior to the 12 mm bolted specimens, although the primary failure mentioned in the load-deformation curve occurred as a splitting failure in the lamina between the steel plate and the reinforcement. Because of the reinforcement and outermost lamina that were still intact, the load was maintained, and afterwards the complete failure of the specimen was observed. Based on these findings, it was possible to ascertain that the reinforcing material had inhibitory effects where the spreading of splitting is curbed from transitioning into the outermost lamination material. As seen in the case of Mode III show, the lower part of the washer was embedded due to the behavior of the bolt as the tensile load increased. As such, it is believed that this failure can be complemented be augmented by augmentingation the washer. Mode IV, in accordance with the configuration and thickness of the reinforcement, is expected to undergo variations in the curvature of the bolt and the inhibitory effects on the spreading of splitting of the timber, and is expected to see increases in the reinforcing effects as well.

3.3. The 5% Yield Load of Bolted Connection

In the case of the bolted connection of 12 mm, the average yield shear strength of the 7D end distance of the control material was 25.62 kN, and the control 5D showed a decrease of 16% compared to 7D. When the bolt diameter is increased to 16 mm while the end distance is the same, it was possible to ascertain that the rates of increase for the average yield shear strength increased significantly, by 59% and by 41% for 5D and 7D, respectively. The average yield shear strength of the 7D of the GS glulam was increased by 12% with the CO specimen as the basis, while that of the 5D was increased by 16%. When the bolt diameter increased in the GS specimen, the rates of increase for the average yield shear strength were 1.54 and 1.62 for the 5D and 7D, respectively, showing similar values to the control specimen. The yield strength of the 7D end distance with 12 mm of the GT glulam was 33.15 kN, which was a 29% increase from the control, and 5D showed an increase of about 26%. As the diameter increased, the GT specimen increased by 1.46 times and by 1.38 times in the cases of 5D and 7D, respectively. Through this, it is confirmed that the shear yield strength is improved when the bolted connection is reinforced with glass fibers as compared to the bolted joint in the non-reinforced glulam. The failure mode of the 12 mm connection, more so than the embedment of the glulam due to the bolt, is a splitting failure in the glulam caused by the yielding of the bolt due to the applied tensile load. As such, in the case of the textile glass fiber reinforced glulam, it is thought that the glass fiber strands that are aligned in the direction perpendicular to the grain inhibit the yielding of the bolt, thus increasing the yield shear strength. The increase in the diameter is expected to exert a more significant effect as the metal fastener increases the of force that acts on the specimen on the shear failure due to embedment than on the splitting failure.

3.4. Coefficient Calculation of Location in Accordance with the Glulam Reinforcement

If the end distance is less than 7D, it is advisable to reduce the yield shear strength by multiplying the coefficient of location (C_{5d}) by the standard yield strength. The yield shear strength that is dependent on the reduction of the end distance was, in accordance with the timber structure design of Korean Building Code (KBC, Architectural Institute of Korea, 2005), calculated using the minimum distance (3.5D) for the standard allowed shear strength when the end distance of the bolt is reduced, and, in the case in which the minimum distance (7D) for the total standard allowed shear strength is the middle, the coefficient of loca-

Table 4. Geometry Factor (C_{5d}) and Results of Nonlinear Regression Analyses

Diameter of bolt	Type of glulam	P_{ry} = An^2 + Bn		R^2	C_{5d}
		A	B		
12 mm	CO	-0.386	6.3615	0.9568	0.86
	GS	-0.7341	8.7985	0.9663	1.00
	GT	-0.9603	10.381	0.9554	1.09
16 mm	CO	-0.9491	11.811	0.9675	0.98
	GS	-1.7383	17.335	0.9579	1.19
	GT	-1.4965	15.642	0.9901	1.13

R^2 = Coefficient of determination
C_{5d} = Ratio of P_{ry} (5D) to P_{ry} (CO, 7D) at the same diameter of a bolt

tion (C_{5d}) was calculated using the following equation and was multiplied by the yield shear strength for the bolted connection.

C_{5d} = the coefficient of minimum end distance (7D) for the total allowable strength and the actual end distance (5D)

As such, the C_{5d} for the 5D end distance of a single bolt connection that was applied to the test of this paper was 0.71. The coefficients of decrease that are dependent on the end distance of the reinforced glulam were compared. Through the correlation of the yield shear strength that is dependent on the 7D of the control material and the 5D of the reinforced glulam, the coefficients of decrease were calculated. For the coefficients of decrease, through the yield shear strength and the quadratic regression model of the end distance, the predicted yield shear strength was obtained as:

$$P_{ry} = b_1 n^2 + b_2 n \quad \cdots\cdots (1)$$

where,

P_{ry} = Predicted yield strength (N) in accordance with end distance

n = e/d

e = End distance (5D or 7D)

d = Bolt diameter

b_1, b_2 = Regression coefficients

Table 4 shows a comparison of the predicted yield shear strength (P_{ry}) obtained through a quadratic regression analysis and the yield shear strength (P_{exp}) obtained through an experiment. It can be seen that in all types, the coefficients of determination are greater than 0.95 and are well matched. The coefficient of location for the 5D end distance (C_{5d}) was used to obtain, with the predicted yield shear strength of the control material of the 7D end distance as the basis, the strength ratio of the predicted yield shear strength of each type of the 5D end distance with the same diameter. With the control material, the coefficients of location (C_{5d}) of 12 mm and 16 mm bolted connections were 0.86

and 0.98, respectively; which showed values that were increased by about 21% and 38%, respectively, as compared to the coefficients of location proposed by KBC; in the case of the reinforced glulam, with the same diameter, the predicted yield shear strength of 5D showed as either the same as the 7D of the control material or an increasing trend. Through these findings, we were able to ascertain that, when reinforcing the control glulam by using textile glass fiber and sheet GFRP as the reinforcing materials - even if 5D is used as the end distance of the bolted connection - a similar strength as the 7D was displayed.

4. CONCLUSION

Using the average yield shear strength of the 12 mm bolted connection of the control glulam as the basis, the sheet GFRP reinforced glulam showed, in the cases of the 5D and 7D end distances, increases of 16% and 12%, respectively, and the textile glass fiber reinforced glulam showed increases of 26% and 29%, respectively. Using the average yield shear strength of the 16 mm bolted connection of the control glulam as the basis, those of the 5D and 7D of the sheet GFRP reinforced glulam showed increases of 22% and 31%, respectively, and the textile glass fiber reinforced glulam showed increases of 15% and 26%, respectively. Using the yield shear strength of the 7D end distance of the control glulam as the basis, the strength ratio of the 5D end distance decreased in the case of the control glulam; however, in the case of the glass fiber reinforced glulam, it showed a trend of increasing to 1.0 ~ 1.2. Through all of these findings, it was confirmed that in the case of bolted connections for the glass fiber reinforced glulam, the shear strength of the 5D end distance is similar to the shear strength of the 7D end distance of non-reinforced glulam proposed in common by each country. The control glulam and the GFRP reinforced glulam underwent momentary fractures after the maximum shear strength; however, the failure mode for the textile glass fiber reinforced glulam displayed a good ductility after the elastic region due to a gradual increase in load, and after the maximum shear strength, it showed a gradual load decrease rate before failing.

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REFERENCES

Architectural Institute of Korea. 2005. Korean Government Guidelines of Korean Buildings Code-Structural. KGG-KBCS-08.

Hernandez, R., Davalos, J.F., Sonti, S.S., Kim, Y., Moody, R.C. 1997. Strength and stiffness of reinforced Yellow-Poplar glued-laminated beams. Res Pap FPL-RP-554. US Department of Agriculture, Forest Service, Forest Products

Laboratory, Madison.

Kim, H.K., Park, C.Y., Lee, J.J. 2008. Evaluation of the strength properties of glulam connections with inserted steel plates and drift pins. Journal of the Korean Wood Science and Technology 36(2): 29～38.

Lantos, G. 1970. The flexural behavior of steel reinforced laminated timber beams. Wood Science 2(3): 136～142.

Mark, R. 1961. Wood-aluminum beams within and beyond the elastic range. Ⅰ. Rectangular Sections. Forest Products Journal 11(10): 477～484.

Masahiro, N., Hiroyasu, S., Akira, W., Kenji, M. 2009. A strength calculation method of single bolted timber joint loaded parallel to the grain. Journal of Structural and Construction Engineering, AIJ 74(638): 681～690.

Mastschuch, R. 2000. Reinforced Multiple Bolt Timber Connections. M.Sc. Thesis, University of British Columbia, Vancouver, BC, Canada.

Ogawa, H. 2000. Architectural application of carbon fibers: Development of new carbon fiber reinforced glulam. Carbon 38: 211～226.

Pedersen, M.B.U. 2002. Dowel Type Timber Connections-Strength Modelling. Ph.D. Dissertation, Rapport BYG・DTU R-039, Technical University of Denmark, Denmark.

Soltis, L.A., Hubbard, F.K., Wilkinson, T.L. 1986. Bearing strength of bolted timber joints. Journal of Structural Engineering 112(9): 2141～2154.

Wilkinson, T.L. 1986. Load distribution among bolts parallel to load. Journal of the Structural Division, ASCE 112(4): 835～852.