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Evaluation of The Moment Resistance Joint Strength of Larch Glulam Using Glass Fiber Reinforced Wood Plate[1]

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ABSTRACT

As a way of developing wooden joint development, a glass fiber reinforced wood plate was manufactured to replace a steel plate. Also, the fracture toughness was evaluated. Through application to a cantilever-type specimen made of a column and a beam, the moment resistance performance was evaluated.

For the fracture toughness specimen of the wood plate, 12 types were manufactured by varying the combination of a main member (veneer and plywood) and reinforcement (glass fiber sheet and glass fiber cloth). The results of the fracture toughness test indicated that the 5% yield load of the specimen using plywood was 18% higher than that of the specimen using veneer, and that the specimen reinforced by inserting glass fiber sheets between testing materials (Type-3-PS) had the highest average 5% yield load 4841 N. Thus, a moment resistance strength test was performed by applying Type-3-PS to a column-beam joint. The results of the test indicated that compared to the specimen using a steel plate and a drift pin (Type-A), the maximum moment ratio of the specimen using a glass fiber reinforced wood plate (Type-3-PS) and a drift pin (Type-B) was 0.79; and that a rupture occurred in the wood plate due to high stiffness of the drift pin. The maximum moment ratio of the specimen using a glass fiber reinforced wood plate (Type-3-PS) and a glass fiber reinforced wooden laminated pin (Type-C) was 0.67, which showed low performance. However, unlike Type-A, a ductile fracture occurred on Type-C, and the load gradually decreased even after the maximum moment.

Keywords : glass fiber reinforced wood plate, fracture toughness, moment resistance performance, glulam

1. INTRODUCTION

The strength performance of a wooden structure depends largely on the strength performance of joints as well as the strength of the members. In most jointing methods other than mortise and tenon, which is a traditional jointing method, a metal jointing material is inserted by making slits between members, and they are combined using a drift pin or a bolt from the side. This jointing method has a high level of reliability due to the high stiffness of the metal jointing material. However, in most cases, brittle fracture, where a fracture occurs in a moment after the maximum strength of a structure, occurs due to

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the relatively low stiffness of the wood. Also, in case of fire, the deformation that starts from a metal jointing material being exposed to the exterior due to high temperature could degrade the stability of the entire structure; and in case of exposure to the open air, the corrosion of a metal jointing material could spread to the wood and could also induce an aesthetic mismatch.

To resolve these problems, Uchisako and Tokuda, 2009 replaced the steel plate of a steel plate insertion-type dowel joint with a GFRP plate, and performed a tensile-type shear strength test of the joint. The results indicated that the ductility of the joint with the GFRP plate insertion was satisfactory, and the yield load (90%) was close to that of the steel plate insertion. Also, as part of wooden joint development, we previously performed a tensile-type shear strength test of a glulam joint using a GFRP-reinforced wood pin and a wood plate; the results indicated that the performance was 12% higher than that of the specimen using a metal jointing material, and that the toughness was good after the maximum load (Song *et al*. 2014). These results suggest that for jointing between wood, a wooden jointing material could be used to replace metal jointing material, and that high performance could be obtained if wood with the same stiffness as that of the main member is used.

On the other hand, for the design of a wooden structure, the bearing strength of a wooden material is an important factor. However, the reinforcement used in a reinforced wooden material does not have a large effect on bearing strength, and thus the reinforcing effect cannot be examined. Therefore, fracture toughness, which is a measure of the resistance of a material to fracture, would be an important factor for the application of a glass fiber reinforced wooden jointing material. In previous studies on fracture toughness, the relation between the width/thickness of a wood plate and fracture toughness has been investigated, and the fracture toughness test of GFRP indicated that glass fiber is a material with high resistance to splitting (Garg, 1986; Leonard *et al*. 2009). Also, among the fracture toughness characteristics of GFRP reinforced larch laminated wood, Kim, observed an increase in the strength and an increase in the toughness (Kim, 2012).

Therefore, in this study, glass fiber reinforced wood plates were manufactured by varying the form, insertion position, and combination form of reinforcement, and the fracture toughness performance was examined. Also, the moment resistance specimen of a column-beam joint using a glass fiber reinforced wood plate was manufactured, and the joint strength was compared with that of a joint using the existing metal jointing material.

2. MATERIALS and METHODS

2.1. Testing Materials

As the testing materials used for the manufacture of glass fiber reinforced wood plates, Radiata pine (*Pinus radiata* D. Don) veneer with a thickness of 2.7 mm and lauan (*Pentacme contorta* (Vidal.) Merr. and Rolfe) plywood with a thickness of 2.7 mm, which are currently available on the market, were used. For the reinforcement, glass fiber cloth with a thickness of 0.5 mm, where glass fiber bundles had been woven in a plain weave. Also, a glass fiber sheet with a thickness of 1.3 mm, where glass fiber had been molded using an epoxy resin, were used.

2.2. Manufacture of The Fracture Toughness Specimen of a Glass Fiber Reinforced Wood Plate

For the manufacturing of fracture toughness specimens, two types of materials (veneer and plywood)

Table 1. Summarizes the nomenclature of the fracture toughness specimens depending on the combination of the main member and the reinforcement

Type	Main member	Reinforcement	Sample label
Type-1	Veneer	Not using	Type-1-V
	Plywood		Type-1-P
Type-2	Veneer	Glass fiber cloth	Type-2-VC
	Plywood		Type-2-PC
	Veneer	Glass fiber sheet	Type-2-VS
	Plywood		Type-2-PS
Type-3	Veneer	Glass fiber cloth	Type-3-VC
	Plywood		Type-3-PC
	Veneer	Glass fiber sheet	Type-3-VS
	Plywood		Type-3-PS
Type-4	Veneer	Both cloth and sheet	Type-4-V
	Plywood		Type-4-P

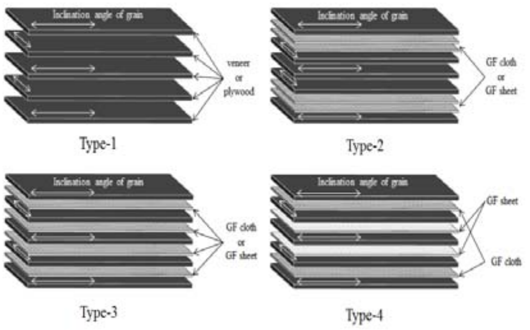

Fig. 1. GFRP reinforced wood plates in accordance with combination of the main member and the reinforcement.

were used; and for the reinforcement, two types of materials were used. A total of 12 types were manufactured through different combinations using four kinds of methods.

Type-1, which is a control specimen, is a specimen in which the testing materials of each lamina was stacked in five laminae crossed in the direction perpendicular to the fiber. For Type-2, the volume ratio of the reinforcement between the outermost lamina and the inner lamina of the testing materials was made to be 12% (glass fiber cloth) and 30% (glass fiber sheets), respectively. For Type-3, the volume ratio of the reinforcement was identical to that of Type-2, but each sheet was inserted between each lamina of the main member. For Type-4, the two kinds of reinforcements were used together, and each glass fiber cloth was inserted between the outermost lamina and the inner lamina of the main member while each glass fiber sheet was inserted between the inner lamina and the middle lamina. For the stacking, a resorcinol resin was used between woods and between wood and glass fiber cloth. A polyvinyl acetate resin was also used between wood and a glass fiber sheet (Park *et al*. 2009). After the application of adhesive, densification of the specimen was performed by applying a pressure of 1.96 N/mm^2 for 1 hour at 150℃.

The manufactured laminated wood was made to be a compact tension-type fracture toughness specimen suggested by ASTM D5045-99. As shown in Fig. 2, for the shape of the specimen, a bolt hole (12 mm) was made on the laminated wood with a length of 200 mm and a width of 100 mm using an

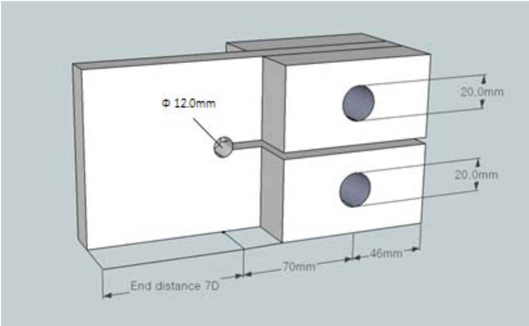

Fig. 2. Configuration of compact-tension test specimens.

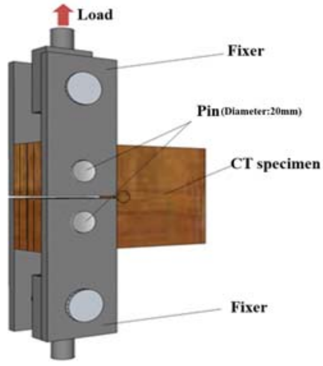

Fig. 3. Setup of fracture test.

end-distance of 7D, and an artificial crack with a width of 4 mm was made on the opposite end-distance.

To apply a tensile load to the specimen, fixing part bolt holes with a diameter of 20 mm were made on both sides of the crack. To prevent fracture at the specimen fixing part during the test, laminae with a thickness of 20 mm and a length of 100 mm were bonded on both sides.

2.3. Fracture Toughness Test of a Glass Fiber Reinforced Wood Plate

The fracture toughness evaluation was performed using a compact-tension test. As shown in Fig. 3, the specimen was installed between the upper load cell and the lower fixing part of a universal testing machine (Instron 4482), where it was fixed using a pin (diameter of 20 mm) so that the specimen could rotate when a tensile load is applied. In this regard, the clearance between the specimen and the side plate of the fixing part was minimized. Furthermore, care was taken not to apply a compressive or tensile load before the test. The load and the crack tip opening displacement (CTOD) were measured using the universal testing machine, and the cross head speed was set to 5 mm/min.

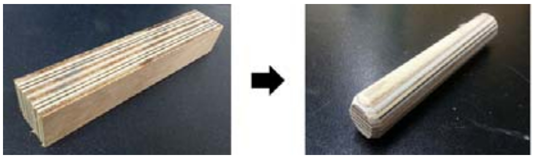

Fig. 4. Shape of glass fiber reinforced wood pin.

2.4. Manufacture of The Moment Resistance Specimen of a Column–beam Joint Using a Glass Fiber Reinforced Wood Plate

Type-A, which used a steel plate and a drift pin as the metal connector; Type-B, which used a glass fiber reinforced wood plate and a drift pin; and Type-C, which used a glass fiber reinforced wood plate and a glass fiber reinforced wood pin, were manufactured. For the column and the beam, a glulam (width of 150 mm and thickness of 170 mm), in which domestic larch (*Larix kaempferi* Carr.) lamina was stacked in six layers, was manufactured and utilized. As shown in Fig. 4, slits were made in the manufactured column and beam, and they were combined using each jointing material. The glass fiber reinforced wood pin was manufactured using the same method as that used for the reinforced wood plate. Then, it was made to be a diameter of 20 mm and a length of 150 mm, as shown in Fig. 4.

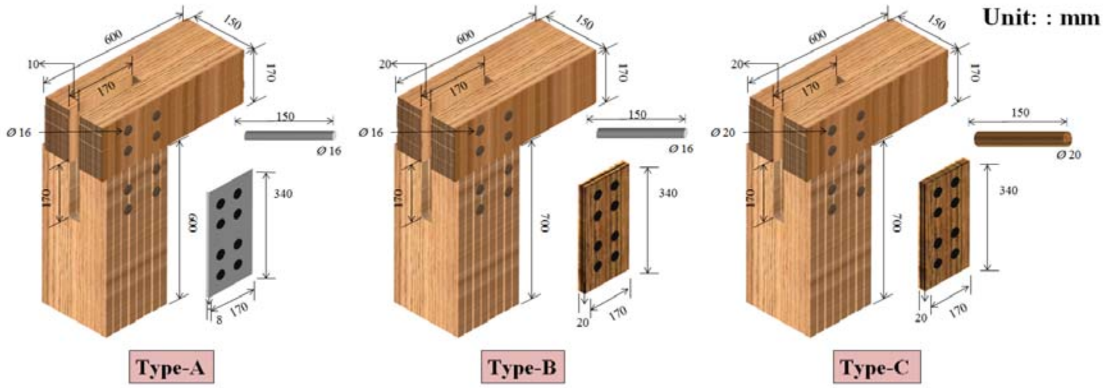

Fig. 5. Specimens of moment resistance performance test.

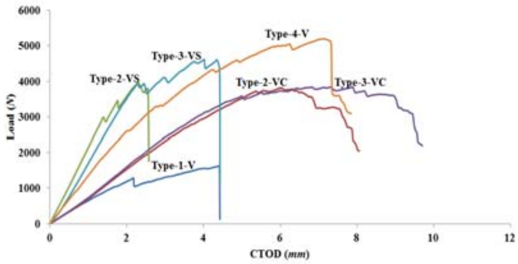

Fig. 6. Load-CTOD curves of Glass fiber reinforced wood plate made by veneer.

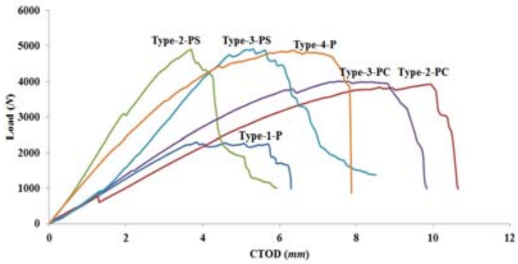

Fig. 7. Load-CTOD curves of Glass fiber reinforced wood plate made by plywood.

2.5. Moment Resistance Strength Test of a Column-beam Joint Using a Glass Fiber Reinforced Wood Plate

The column of the completed specimen was fixed, and a loading rate of 10 mm/min was applied to the beam, which was 300 mm away from the center of the column. To measure the deformation depending on the load, a displacement meter with a capacity of 50 mm was installed as shown in Fig. 5. Furthermore, measurement was made using a data logger (TDS-303).

3. RESULTS and DISCUSSION

3.1. Fracture Toughness Test of a Glass Fiber Reinforced Wood Plate

The average maximum load of the Type-1-V specimen manufactured using only the veneer was 1324 N. The average 5% yield load of it was 1064 N. As the veneer was cross-stacked, splitting did not occur in the fiber direction, and momentary splitting occurred in the direction perpendicular to the fiber. Type-2-VC and Type-3-VC, had been reinforced with the glass fiber cloth. The average maximum loads of them were 3526 N and 3365 N, respectively, They were 2.6 times and 2.5 times higher

Table 2. Results of fracture toughness test

Specimens		Ave. Pmax (N)	Ave. P_Q (N)	Ratio*
Type-1	V	1324	1064	1.00
	P	1993	1898	1.78
Type-2	VC	3526	3362	3.15
	PC	3773	3452	3.24
	VS	3445	3090	2.85
	PS	4373	4046	3.80
Type-3	VC	3365	3086	2.90
	PC	3696	3470	3.26
	VS	3832	3545	3.33
	PS	5242	4866	4.56
Type-4	V	4693	4149	3.89
	P	4741	4097	3.85

Ratio*: Ratio of the average yield load relative to Type-1-V

than that of the Type-1-V specimen. For the two specimens, splitting occurred in the direction perpendicular to the fiber; and a ductile fracture was observed as shown in the load-CTOD curves in Fig. 6 because the glass fiber cloth suppressed splitting. The average maximum loads of Type-2-VS and Type-3-VS, which had been reinforced with the glass fiber sheet, were 3445 N and 3832 N, respectively; and the average 5% yield loads were 3086 N and 3545 N, respectively. For the specimen reinforced with the glass fiber sheet, the stiffness was higher than that of the specimen reinforced with the glass fiber cloth, but splits occurred to the fiber direction. It is thought because fiber orientation of glass fiber sheet was same as longitudinal direction of wood plate. The average maximum load of Type-4-V, which used the two reinforcements together, was 4693 N, which was 3.5 times higher than that of the Type-1-V specimen; and the average 5% yield load was 3.9 times higher. The glass fiber sheet that had reinforced the inner layer increased the stiffness of the wood plate, and the glass fiber cloth of the outer layer suppressed the splitting occurring in the fiber direction.

The average maximum load of the Type-1-P specimen manufactured using only the plywood was 1993 N, and it was 1.5 times higher than that of the Type-1-V specimen manufactured using only the veneer. The average maximum loads of Type-2-PC and Type-3-PC, which had been reinforced with the glass fiber cloth, were 3773 N and 3696 N. They were 1.9 times and 2.2 times higher than that of the Type-1-P specimen, while the average 5% yield loads were 1.8 times and 2.1 times higher, respectively.

Type-2-PS and Type-3-PS had been reinforced with the glass fiber sheet. The average maximum loads of them were 4373 N and 5242 N, respectively. Notably, it is thought that for Type-3-PS, high performance could be obtained because unlike the veneer, the plywood suppressed the splitting occurring in the fiber direction although the glass fiber sheet was used. The average maximum load of Type-4-P was 4741 N. The fracture shape showed a similar trend to that of Type-4-V, but the bonding layer of the plywood was ruptured. Because the bonding strength of the interior of the plywood was lower than the bonding strength between the reinforcement and the plywood.

3.2. Results of The Moment Resistance Strength Test

The maximum moment of Type-A, which used a steel plate and a drift pin was 10.6 kN · m and the deformation angle was 0.04 rad. The initial stiffness was the highest (204.6 kN · m/rad.) but a large rupture occurred at the end-distance of the column and the beam. This fracture shape is typical for a fracture of a wooden structure joint using a metal jointing material. It could be because the stiffness of a metal jointing material is much higher than that of wood. For Type-B, a wood plate that had been made

Table 3. Properties of moment resistance test

Specimens	Initial stiffness (*kN・m/rad.*)	Mmax (*kN・m*)	Rotation angle (*rad.*)
Type-A	204.6 (1.00)*	10.6 (1.00)**	0.04
Type-B	98.4 (0.48)*	8.4 (0.79)**	0.05
Type-C	101.4 (0.50)*	7.2 (0.68)**	0.14

Ratio*: Ratio of the initial stiffness relative to Type-A
Ratio**: Ratio of the maximum moment relative to Type-A

using the same method as that of Type-3-PS was used. Also, a drift pin was used as the connector. The maximum moment of Type-B was 8.4 kN・m, and the deformation angle was 0.05 rad. Unlike Type-A, a rupture occurred at the end-distance of only the column. After the fracture of the column, the wood plate was ruptured in the fiber direction of the glass fiber sheet by the drift pin, similar to the earlier fracture toughness test. This occurred because the drift pin with high stiffness pressed the relatively weak wood plate. It is thought that the rupture in the fiber direction could be suppressed if the fiber direction of the glass fiber sheet inserted in the wood plate is stacked perpendicularly to the longitudinal direction of the wood plate, or is stacked obliquely. The maximum moment of Type-C, which used a glass fiber reinforced wood plate and a glass fiber reinforced wood pin, was 7.2 kN・m, and the deformation angle was 0.14 rad. The initial stiffness was 101.4 kN・m/rad., which was reduced by 50% compared to that of Type-A; and the maximum moment was reduced by 33%. For the fracture shape, a rupture only occurred at the end-distance of the column, similar to Type-B. The glass fiber reinforced wood plate was not fractured, while the glass fiber reinforced wood pin was fractured. The glass fiber reinforced wood pin had 8 times less bending strength than the drift pin. However, in the application to a glulam joint, the performance was about 70% that of a metal jointing material. It is thought

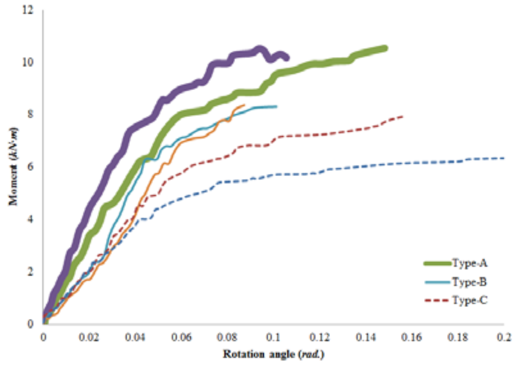

Fig. 8. Moment-rotation angle curves of moment resistance tests.

that if the strength/stiffness difference from a metal connector was decreased by improving the reinforcing method during the manufacture of a glass fiber reinforced wood pin in the future, the joint strength performance of a glulam could also be increased.

4. CONCLUSION

As part of wooden joint development, a glass fiber reinforced wood plate was manufactured to replace a steel plate, and the fracture toughness performance was evaluated. After manufacturing a column-beam specimen that incorporates this, the moment resistance joint strength performance was evaluated.

The result of the fracture toughness test indicated that the specimen using the plywood showed 18% higher performance than the specimen using the veneer. Also, it indicated that of the reinforcement combination methods, the method in which the glass fiber sheets had been inserted between each layer of the testing materials showed the highest performance. However, in the future, it will be desirable to improve the performance of a wood plate through various studies on methods of reinforcement using veneer rather than plywood. The results of the moment resistance test indicated that the maximum moment of the specimen using the wooden jointing material showed 33% lower performance than the specimen using the metal jointing material. However, unlike the metal joint, which undergoes a brittle fracture, a ductile fracture occurred. Also, the fracture of the glulam by the wood pin was smaller compared to the specimen using the metal jointing material, and the load decreased gradually even after the maximum load. However, above all, the strongest point is that the advantage of a wooden structure can be highlighted due to its excellent aesthetic characteristics. Therefore, it is thought that the usage would increase if performance comparable to that of a metal jointing material can be obtained by improving the fiber direction splitting occurrence of a glass fiber reinforced wood plate and by increasing the durability of a wood pin.

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