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BENDING MOMENT RESISTANCE OF T-TYPE JOINTS REINFORCED WITH BASALT AND GLASS WOVEN FABRIC MATERIALS

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ABSTRACT

This study investigated the bending moment resistance of T-type, two-pin dowel joints connected with Scotch pine dowel (*Pinus slyvestris*), beech dowel (*Fagus orientalis*), chestnut dowel (*Castanea sativa*) and oak dowel (*Quercus petraea*) and reinforced with basalt and glass woven fabric. The tests was carried out to determine the bending moment resistance of dowel joints. As a result of bending test, it was determined that one layer and two surfaces the reinforce with fiber woven fabrics increases the mechanical performance of furniture fasteners according to obtained data from tests conducted on the T-type, two pin dowel joints. The test samples prepared from the oak wooden give the higher moment values than the beech wooden. This study showed that the joining with the oak dowel was 13 % higher than the beech dowel, 32 % the chestnut dowel, and 43 % higher than the Scotch pine dowel (for the bending moment resistance), respectively. According to the bending moment resistance of the samples reinforced by fiber woven fabrics. The highest bending moment resistance value was obtained in the test specimens of reinforced with the basalt woven fabric, the lowest bending moment resistance value was obtained in the test specimens not reinforced (Control). In general, it was determined that the wood species by 3 %, wooden dowel species by 43 %, and fiber woven fabric types by 72 % have been effects on the results of the bending tests.

Keywords: Basalt woven fabric, bending moment resistance, glass woven fabric, two-pin dowel joint, wooden dowel.

INTRODUCTION

Dowel joints have been one of the most widely used connection in the furniture industry for joining wooden structural members in the furniture (Chen *et al.* 2018, Hao *et al.* 2020). The strength and stiffness of these joints are determined by the dowel spacing, the the depth of penetration, wood species, adhesive type, tight fit etc. (Zhang *et al*. 2003). The resistance of the bending moment or stiffness of the dowel joint was increased by stages with the rising diameter and length of dowel (Chen *et al*. 2018).

The T-type, two-pin dowel joints strength is affected by a few parameters including the type of adhesive and properties of wood and wood composite materials by used, also a variety of dowel joint process parameters such as dowel spacing, dowel dimension, dowel position and dowel joint geometry configurations (Vassiliou *et al.* 2016, Uysal and Haviarova 2018, Záborský *et al.* 2018, Hao *et al*. 2020), solid wood and wood based composite used in (Vassiliou *et al.* 2016, Uysal and Haviarova 2018, Záborský *et al.* 2018), dowel joint geometry configurations (Vassiliou *et al.* 2016, Záborský *et al.* 2018, Hao *et al.* 2020), rail widths (Zhang *et al*. 2003), configurations of joints (Yerlikaya and Aktas 2013), different cyclic load (Vassiliou *et al*. 2016).

Fiber reinforced polymer (FRP) materials include carbon, glass and aramid FRPs and provide advantages over the traditional repair materials in terms of better mechanical and chemical performance and easier constructability (Sim 2001). Basalt-based materials are environmentally friendly and non-hazardous. The current

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production technology for continuous basalt fibres is very similar to that used for E-glass manufacturing. The main difference is that E-glass is made from a complex batch of materials whereas basalt filament is made from melting basalt rock with no other additives and, as a consequence, with an advantage in terms of cost. Their specific mechanical properties are comparable with, or better than, those of E-glass ones. The glass fiber reinforce polymer (GFRP) material value of density, elasticity modulus, tensile strength and elongation to fracture were 2,6 g/cm^3, 76 GPa, 2,0 GPa, and 2,5 %, respectively (Fiore *et al.* 2011) . The basalt fiber reinforced polymer (BFRP) value of density, elasticity modulus, tensile strength, and elongation to fractre were 2,8 g/cm^3, 89 GPa, 2,8 GPa, and 3,2 %, respectively (Colombo *et al.* 2012).

Recently, A great deal of investigations has been studied wooden reinforced with the FRP Among the others, Basterra *et al*. (2012), Nowak *et al*. (2013), Osmannezhad *et al*. (2014), McConnell (2015), Raftery and Kelly (2015), Schober *et al.* (2015), Brol and Wdowiak (2017), Brol *et al*. (2018), Zhou *et al.* 2018, Wdowiak and Brol (2019), Gaff *et al.* (2019), Wang *et al*. (2019), Zhou *et al.* (2019), Zhou *et al.* (2020), Wdowiak-Postulak (2021) have studied the FRP reinforcement under several test configurations such as different density, layer number, and loaded. On the bending moment resistance of T-type, two-pin dowel joints with reinforced basalt fiber woven fabric are not applied and it is considered that there is a deficiency in the literature. The BFRP with reinforced joints in frame-type furniture is a new research topic.

The aim of study is to determine the effects of wood species, wooden dowel species and fiber woven fabric types (BFRP and GFRP) on the bending moment resistance of the T-type joints, two-pin dowel joints.

MATERİALS AND METHODS

The woods of oak (*Quercus petraea* Liebl.), beech (*Fagus orientalis* Lipsk), chestnut (*Castanea sativa* Mill.), and Scotch pine (*Pinus sylvestris* Lipsky) were chosen randomly from timber merchants of Karabük in Turkey (Figure 1a). Special emphasis is given for the selection of the wood material. The test specimens were selected natural color uniformity, smoothness of fibers, absence of knots, heart uniformity, absence of reaction wood, and absence of fungal and insect damage. It has beeen paid attetion that the wood material used in experimental studies is not exposed to physical damage, mechanical impacts, or biological damage.

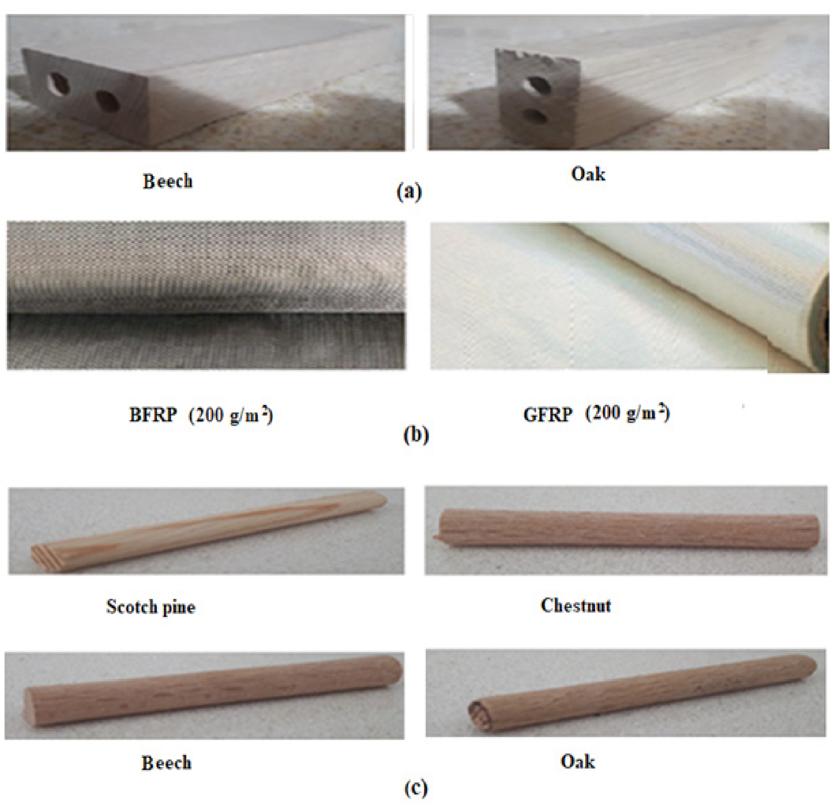

Figure 1: Materials used in experiments (a) wood species, (b) basalt and glass woven fabric, (c) wooden dowel species.

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Moisture contents (MC) and densities of the wooden materials were tested according to TS 2471 (1976) and TS 2472 (1976) standards, respectively.

Measured average densities were: oak 690 (kg/m^3), beech 670 (kg/m^3), average moisture contents were: oak 11,8 %, beech 11,5 %, respectviley. The two wood species were cut on boards of 25 mm thickness x 50 mm width.

Wooden dowel species were supplied from a local shop in timber enterprises in the Karabuk, Turkey. Dowels with threaded bodies having a diameter of 8 mm, lengths of 40 mm and the moisture content of 8 % to 12 % was used in the experiments (Figure 1). Dowels were prepared from chestnut, oak, Scotch pine and beech woods. Measured average densities were: oak 690 (kg/m^3), beech 670 (kg/m^3), chestnut 570 (kg/m^3), Scotch pine 500 (kg/m^3), average moisture contents were: oak 11,8 %, beech 11,5 %, chestnut 10,2 %, Scotch pine 9,3 %, respectively.

The BFRP and GFRP for 200 (g/m^2) plain materials used in the study was obtained by Dost Chemical Industry Raw Material Industry and Trading Company (Turkey, Istanbul) (Figure 1c). The BFRP and GFRP were prepared by cutting to 100 mm in length and 50 mm in width.

The adhesives used in this test were polyvinyl acetate adhesive (PVAc-D4) which is commonly used in the wood industry and case type furniture manufacture (Kronen Furniture Glue Accessory Industrial Products Industry and Trade Ltd Co., Izmir, Turkey) and epoxy adhesive L285 resin + H285-hardener (Dost Chemical Industry Raw Material Industry and Trading Co., Istanbul Turkey). The technical parameters of the two adhesives are shown in Table 1.

Table 1: Technical data and characteristics of the adhesives.

Technical Data	Polyvinyl acetate (PVAc-D4)	Epoxy (L285 resin+ H285 Hardener)
Viscosity (mPas)	15000-16000 at 20 °C	600 - 900 at 25 °C
Working time (min)	35-40 at 20 °C	45-240 at 25 °C
Density (g/cm^3)	1,08 at 20 °C	1,21 at 25 °C
Solids content (%)	50	-
pH	3,5	-
Main agent/Hardener Ratio (w/w)	100/5	100/50

Preparation and construction of specimens

The T-type, pin-dowel joints structure, comprising the rail and post members, as shown in Figure 2. Dimensions of the posting member and the rail were 150 mm × 50 mm × 25 mm and 125 mm × 50 mm × 25 mm, respectively. Members were combined with each other with two wooden dowels with a nominal diameter of 8 mm and a length of 40 mm. The dowels were produced from wood species measured 100 mm long by 11 mm wide by 11 mm thickness of wood pieces with using a dowel drawing machine. The distance between the centerlines of the two dowels were 20 mm. Joints specimens were constructed of oak and beech. The rail and post members were drilled with a drilling machine. Depths of the dowel holes in both the post and the rail was 21 mm. Then the holes in the member were cleaned with compressed air. All specimens were assembled with a polyvinyl acetate adhesive (PVAc-D4). The walls of the holes and the sides of the dowels were liberally coated with adhesive prior to insertion of the dowels. In all samples, a piece of wax paper was included between the two members to prevent any possibility of the members adhesion. Then, areas where BFRP and GFRP were to be placed were bonded with a blend of epoxy adhesive and hardener. Joint instances were left to dry for two days. Test samples are not reinforced, one layer and two surfaces reinforced with BFRP or GFRP in Figure 2.

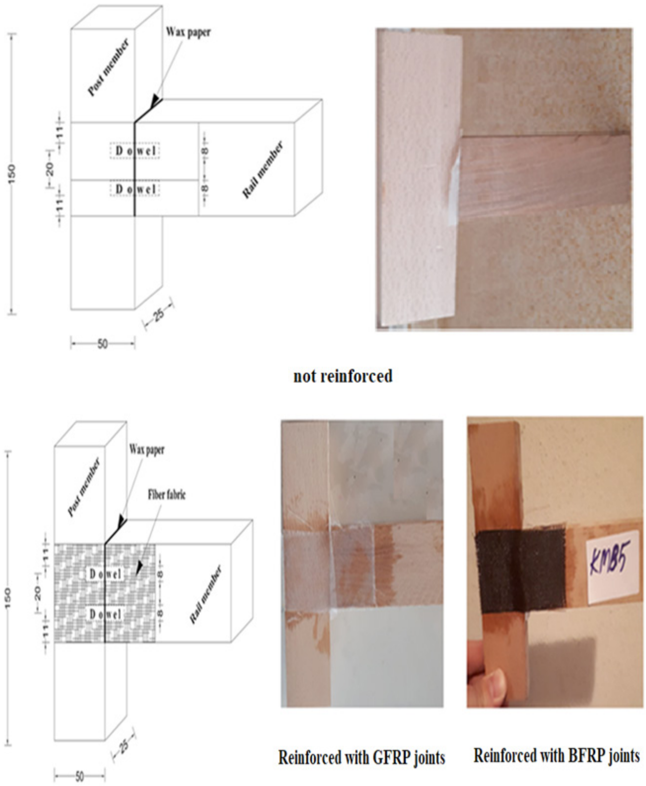

Figure 2: Diagram showing the construction of T-type joints (dimensions in mm).

According to this, two wood species, four wooden dowel species, and two fiber woven fabric types (BFRP, GFRP, and control), and 5 samples of each material (2 x 4 x 3 x 5) were the variables, totally a number of 120 samples were constructed in this research. Prior to testing, all samples were conditioned in a humidity chamber controlled at 20 °C ± 2 °C and 65 % ± 5 % relative humidity (RH) for two weeks.

Method of testing

All tests were conducted on a SHIMADZU universal test machine (SHIMADZU Corp., Sydney, Australia). Specimens were held for testing as shown in Figure 3. In all of the T-type, two pin dowel joints tested on a SHIMADZU universal test machine (SHIMADZU Corp., Sydney, Australia) at a loading rate of 8 $mm \cdot min^{-1}$. Loads were applied to the stump 125 mm in front of the rail. Load-displacement curves of tested joints and their failure modes were recorded. The bending moment resistance values were found using as follows (Equation 1).

$$M = F \ x \ L \qquad (1)$$

Where *M* is the bending moment resistance (N·m), *F* is the ultimate applied force (N) and *L* is the moment arm (m).

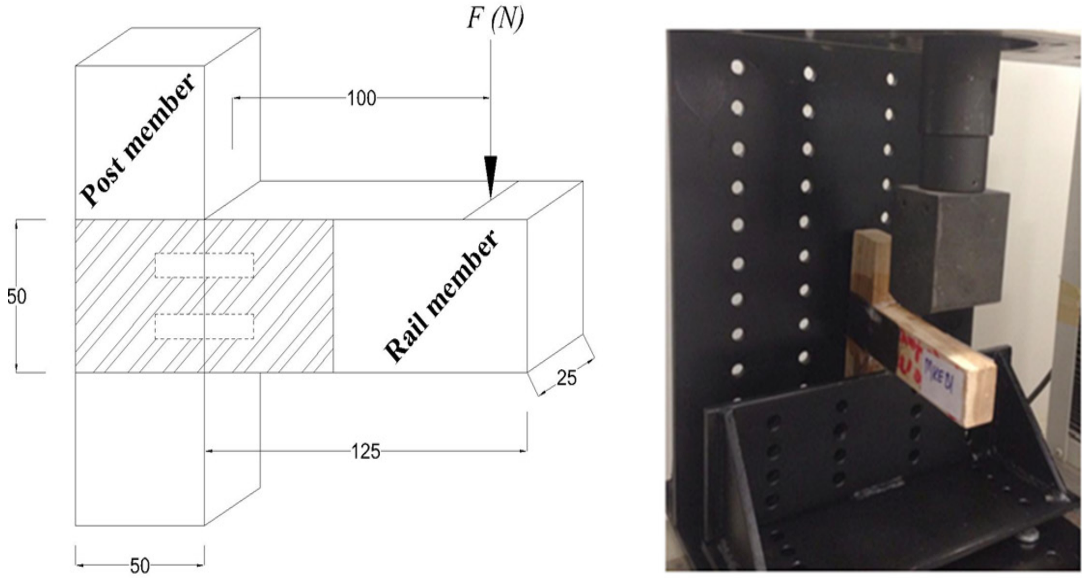

Figure 3: Way of support and loading the specimens of the corner joints.

Statistical analyses

A two way analysis of variance (ANOVA) statistical analysis was used applying the statistical package IBM SPSS 22. The effects of the wood species, the wooden dowel species and the fiber woven fabric types on the bending moment resistance were determined by analysis of variance (α=0,05). The bending moment resistance influence levels of the factors were determined by applying the Tukey Homogeneity Test to the influential factors within the groups and among the groups.

RESULTS AND DİSCUSSİON

The mean values bending moment resistance under compression of T-type joints with their standard deviation and coefficients of variation were presented in Table 2.

According to multiple comparisons on the bending moment capacities, the highest bending moment resistance value was obtained from oak wooden jointed with an oak dowel and reinforced with BFRP (157,37 N·m), while the lowest value was acquired in beech wooden with Scotch pine dowel and not reinforced (control) (55,94 N·m).

Table 2: Mean values of the bending moment resistance of joints with their coefficients of variation.

Wood Species	Wooden Dowel Species	Fiber Woven Fabric Types	Mean (N·m)	SD	COV (%)
Beech	Chestnut	Control (No-SMT)	67,78	6,68	9,86
		GFRP	92,97	2,70	2,90
		BFRP	104,31	6,81	6,53
	Beech	Control (No-SMT)	75,51	3,65	4,83
		GFRP	92,94	7,49	8,06
		BFRP	134,09	9,85	7,35
	Oak	Control (No-SMT)	84,41	2,84	3,36
		GFRP	114,41	6,53	5,71
		BFRP	149,54	5,88	3,93
	Scotch pine	Control (No-SMT)	55,94	2,86	5,11
		GFRP	85,92	7,68	8,94
		BFRP	99,19	7,61	7,67
Oak	Chestnut	Control (No-SMT)	69,26	8,27	11,94
		GFRP	88,78	5,64	6,35
		BFRP	113,22	6,88	6,08
	Beech	Control (No-SMT)	75,69	5,18	6,84
		GFRP	105,53	8,67	8,22
		BFRP	132,12	7,18	5,43
	Oak	Control (No-SMT)	83,28	2,56	3,07
		GFRP	109,78	5,69	5,18
		BFRP	157,37	4,32	2,75
	Scotch pine	Control (No-SMT)	59,17	4,65	7,86
		GFRP	79,85	6,37	7,98
		BFRP	109,59	5,03	4,59

SD: Standart deviation, COV: Coefficient of variation, SMT: Supporting material type.

The results of the multi-way ANOVA analysis of the wood species, the wooden dowel species, and type of fiber reinforced polymers on the bending moment resistance of the T-type, two pin dowel joints under the compression load were given in the Table 3.

Table 3: Summary of the ANOVA results for moment resistance.

Source	df	Sum of Square	Mean Square	F	Sig.
Corrected Model	23	84342,048	3667,046	95,551	0,000
Intercept	1	1136504,907	1136504,90	29613,664	0,000
Wood Species (A)	1	208,587	208,587	5,435	0,022
Wooden Dowel Species (B)	3	21557,592	7185,864	187,241	0,000
Fiber Woven Fabric Types (C)	2	58761,030	29380,515	765,562	0,000
A×B	3	44,305	14,768	0,385	0,764
A×C	2	238,629	119,315	3,109	0,049
B×C	6	2670,815	445,136	11,599	0,000
A×B×C	6	861,090	143,515	3,740	0,002
Error	96	3684,261	38,378		
Total	120	1224531,216			
Corrected Total	119	88026,309			

R Squared = 0,958 (Adjusted R Squared = 0,948) df: Degrees of Freedom.

According to the analysis of variance as presented in Table 3, the effects of the main factors including the wood species (A), the wooden dowel species (B), and the fiber woven fabric types (C) were found to be statistically significant, while wood species × wooden dowel species (A×B) was insignificant at the level of 0,05. Two-way interactions of wood species × fiber woven fabric types (A×C), and wooden dowel species × fiber woven fabric types (B×C) were statistically significant at the level of 0,05. Three factor interactions of wood species × wooden dowel species × fiber woven fabric types (A×B×C) were also statistically insignificant ($p \leq 0,05$). Tukey test was carried out in order to determine these differences. The bending moment resistance means according to independent effects of test variables were given in Table 4.

Table 4: The results from the Tukey's test for independent effects of test variables.

Source		Bending moment capacity (N·m)	SD	HG
Wood species	Oak	98,64	5,88	A
	Beech	96,00	5,87	B
Wooden dowel species	Oak	116,46	4,64	A
	Beech	102,65	7,00	B
	Chestnut	88,56	6,16	C
	Scotch pine	81,61	5,70	D
Fiber woven fabric types	BFRP	124,93	6,70	A
	GFRP	96,27	6,35	B
	Control	70,75	4,59	C

SD: Standart deviation, HG: Homogeneity groups.

When the comparison results of wood species were examined, it was seen that the highest bending moment resistance value was obtained for oak (98,64 N·m). The bending moment resistance of beech wood was much lower. The oak wood was 3 % stronger than the beech wood (Table 4). The density of oak wood was higher than the density of the beech wood used in the experiments.

For the wooden dowel species, the oak dowel showed significantly higher the bending moment resistance value than other dowels (Table 4). The bending moment resistance value of oak was approximately 13 %, 32 % and 43 % higher than for joints constructed with beech, chestnut and Scotch pine, respectively. The situation with the species of lumber used for dowels can explain with the structural properties of the materials. The reasons for these may be based on the density of wooden materials. As a general rule, mechanical properties increase as the density of solid wood material increases. There is an increasing-linear relationship between bending strength, modulus of elasticity and shock resistance and density. In previous studies, many researchers have identified this relationship (Kollmann and Cote 1968, Bozkurt and Erdin 1995, Bektaş *et al.* 2002, Bal and Bektaş 2018).

According to fiber woven fabric, the highest bending moment resistance value were obtained in basalt fiber woven fabric (BFRP) (124,93 N·m), and the lowest was in control samples (70,75 N·m). The mean bending moment resistance of joints with BFRP was 30 % and 77 % higher than joints with GFRP, and not reinforced joints (control), respectively.

Dorigato and Pegoretti (2012) explained that the basalt fibers have exhibit mechanical properties fully comparable with those of glass fibers, the elastic modulus of basalt and the tensile strength were greater than glass fibers. Chairman and Kumaresh Babu (2013) obtained that compressive and tensile ultimate strength of BFRP laminates are higher than GFRP laminates of about 43 % and 23 %, respectively. Borri *et al.* (2013a) investigated flax and basalt FRP strengthened low-grade (bending strength of 18,4 MPa) and high-grade (bending strength of 41,3 MPa) wood beams. The results showed an increase of bending strength of 38,6% and 65,8%, This study concluded that both BFRP and FFRP provided the beams with higher strength and better ductile behavior. Similar results can be found in another research by Borri *et al.* (2013b) for flax and basalt FRP. André and Johnsson (2010) applied FFRP and GFRP with similar fabric density (i.e., 230 g/m^2 for flax and 250 g/m^2 for glass) perpendicular to grain on wood beams. It is reported that the maximum bending load of the entire specimen strengthened with GFRP (45,1 kN) was 23 % higher than that one strengthened with FFRP (36,0 kN). McConnell *et al.* (2015) in their investigations into the reinforcement of wooden beams with BFRP tensile basalt fibres noted an increased load capacity and rigidity of 28 % and 8,7 %, respectively. Monaldo *et al*. (2019) explained that beams reinforced with BFRP have a bending ultimate load higher of by about 20 % than the case of GFRP.

Wdowiak-Postulak (2021) found that the load carrying capacity of beams reinforced with basalt fibre was higher by, respectively, 13 % and 20 % than that of reference beams, while their rigidity improved by, respectively, 9,99 % and 17,13 %.

The most popularly used high-strength fibers are carbon fiber, glass fiber, and basalt fiber. In comparison to other fibers, basalt fiber has superior characteristics, that is, high strength to weight ratio, excellent ductility and durability, high thermal resistance, chemical resistance, good corrosion resistance, fire resistance, high temperature resistance, high performance in terms of strength, and cost-effectiveness (Fiore *et al*. 2011, Wang *et al*. 2013), as well as the lower potential cost with respect to other fibre-reinforced polymer (FRP) materials (Fiore *et al*. 2015).

The cost of elements used in traditional reinforcement methods is low compared to that of FRP materials. But in the long run, elements such as bolts, nails, etc. may not be effective on timber. Therefore, it is more convenient to use FRP materials instead of traditional reinforcement methods as they require maintenance and repair over time and have low durability.

Failure modes

After testing, all connections were visually inspected in order to identify the failure mode of the dowels. In the bending moment resistance test of T-type two pin dowel joints construction with Beech and Oak wood in not reinforced samples deformations as in Figure 4 were observed. While there was no deformation in the wooden members, bending deformation in the dowel used for the joint was observed. For all of the joint types, failures initially occurred as opening at the inner face of joints when those joints were subjected to bending moment. The width of the gap between the rail and the post was measured to obtain the degree of decay of the dowel joints. As result, it was seen that the highest rate of the gap was in Oak wood + Beech dowel test samples (Figure 4a2). Oak wood+Chestnut dowel, Beech wood+Beech dowel, Beech wood+Oak dowel, samples followed respectively (Figure 4a3, Figure 4b2, Figure 4b1). Other samples were observed lower. It can be said that the gap rate in other examples is lower.

Figure 4: Mode of T-type, two pins dowel joint failure not reinforced.

The deformations of dowel joints the reinforced with GFRP strengthened are shown in Figure 5. According to the reinforced joints, glass fiber woven fabric has prevented cracking. It was observed for all of the joint types, failures not occurred as opening at the inner face of joints when those joints were subjected to bending moment. The gaps were much shorter than the not reinforced samples. For the samples of the Oak wood+Chestnut dowel+GFRP, cracks occurred on the inner face of the face members (Figure 5c). The deformations of dowel joints the reinforced with GFRP strengthened are than not reinforced samples. It is seen that the deformation of the dowel joints reinforced with GFRP is less than the samples un reinforcement.

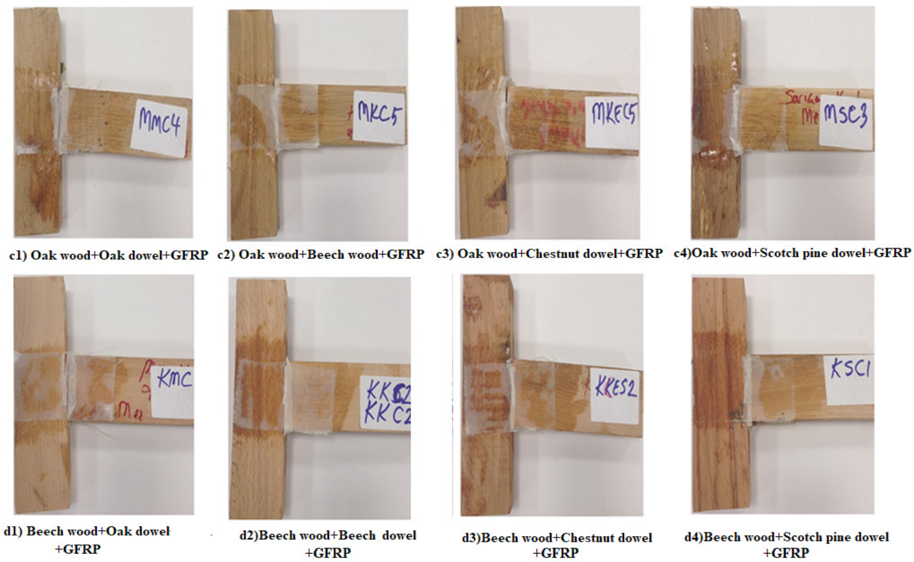

Figure 5: Mode of T-type, two pin dowel joint failure reinforced with GFRP.

The deformation of the T- type two pin dowel joints with inforced by basalt woven fabric under bending strength test is shown in Figure 6. According to test results, the failures that occurred as a split of particleboard in both the face and butt members. In the joints of the test samples reinforced with BFRP, failures have occured on the outer face of the basalt woven fiber fabric. In all of the samples the beech joints reinforced with BFRP (Figure 6f), the failures are almost identical. For the samples of constructed with oak wooden, it is seen that the failures occurred as a result of cracking at the junction of the middle of the basalt woven fabric are more in the Oak wood+Oak dowel+BFRP (Figure 6f1) and Oak wood+Chestnut dowel+BFRP (Figure 6f3) samples.

Figure 6: Mode of T-type, two pin dowel joint failure reinforced with BFRP.

CONCLUSİONS

Wood material is among the most widely used building materials due to the fact that it is renewable, low cost, natural, easy to recycle and aesthetic. It is known that one of the most important advantages of reinforcement with basalt and glass fabrics is to strengthen and repair the wood material. Although the application of these methods brings a cost burden to the user, it increases the useful life of the wood structure. For this aim, it is an ideal reinforcement element for wood materials since it has a high degree of hardness and higher strength compared to its light weight and it is a non-abrasive corrosion resistant flexible material which ensures the reduction of long-term maintenance costs and provides fast installation on site. Also, these materials demonstrate high durability in corrosive environments thanks to their high resistance to fatigue. The production of reinforced wood materials with high economic value and their increasing use can benefit economically.

The bending moment resistance of T-type, two-pin dowel joints constructed four wooden dowel species and reinforced with basalt fiber woven fabric and glass fiber woven fabric was investigated. Experimental results indicated that traditional glued Oak dowel joints yielded the highest bending moment resistance among Beech dowel, Chestnut dowel and Scotch pine dowel joints. Scotch pine dowel joints had the lowest bending moment resistance among the joints evaluated. The mean comparison showed that Beech dowel joints could produce a higher bending moment resistance than Chestnut dowel joints. The bending moment resistance value of reinforced joints (for GFRP and BFRP joints, respectively) were 30 % and 77 % higher than not reinforced joints.

Researchers could be provide a range of optimum values, for the parameters (wood species, four different wooden dowel species, fiber woven fabric types) affecting frame furniture joint bending moment resistance and this colud be helpful for engineering design of furniture structures. Future studies will have to investigate the bending moment resistance of L-shaped two-pin dowel joints reinforced with different FRP materials.

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