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Determination of Bending Moment Resistance of L-Type Doweled Joints Reinforced With Glass-Fiber-Reinforced Polymer Woven Fabrics (GFRPWF) and Basalt-Fiber-Reinforced Polymer Woven Fabrics (BFRPWF)

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Abstract: In this study investigated the bending moment resistance of L-type doweled joints reinforced with glass-fiber-reinforced polymer woven fabrics (GFRPWF) and basalt-fiber-reinforced polymer woven fabrics (BFRPWF). Dowels produced from Scots pine, oak, beech and chestnut wood were used in the doweled joints. While the GFRPWF and BFRPWF were fixed with epoxy adhesive, the dowels were fixed with polyvinyl acetate (PVAc-D3/D4) glue. Test were carried out to determine the bending moment resistance of doweled joints. Experimental results showed that joints connected with oak dowel has been the highest bending moment resistance, and the joints of Scots pine dowel has been the weakest bending moment resistance. The bending moment resistance of oak dowel was approximately 23%, 33%, and 61% higher than for joints constructed with beech, Chestnut and Scots pine, respectively. The bending moment resistance value reinforced with the BFRPWF (55.62 N.m), and the lowest was in unreinforced joints (32.06 N.m). The mean bending moment resistance of reinforced joints (GFRPWF, BFRPWF) was 31% and 74% higher than unreinforced samples (control), respectively. In general, it has been found that the bending moment resistance of doweled joints is influenced by wooden dowel species and FRP types.

Keywords: BFRPWF, dowel, GFRPWF, polyvinyl acetate, Scots pine, wooden.

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1. INTRODUCTION

Nowadays, only wood material and no other building material can be used. It is possible to build a house without using it. other structure Materials may not have such wide usage opportunities. Of wood; From facade cladding to interior spaces, from ceilings to floors, kitchen Dozens of usage areas from furniture to verandas and pergolas available (Beram, 2021).

Wooden structures are vulnerable to degradation over time due to prolonged exposure to loading conditions and fluctuations in environmental factors, such as temperature and humidity. These deteriorations can compromise the structural integrity of wood-based materials, giving rise to safety concerns that necessitate their early identification (Beram, 2023).

Wood material, as a natural, renewable and sustainable resource, has been in human life for thousands of years and still is. It is a building and engineering material that maintains its importance. From ancient times to the present, human beings have needed both shelter and comfort. It needed wood material and a wide variety of products produced from this material for life (İçel and Beram, 2016).

Fiber reinforced polymer (FRP) is composite with mature technology and wide application. FRP was widely used in civil industry, such as transportation industry bridges (Yang et al., 2020), roads (Mohamed and Masmoudi, 2011), light industry, chemical industry (Gilby, 1999), medical treatment (Jiang et al., 2021) electricity and other industries. FRP has the light weight, corrosion resistance, fatigue resistance, enabling FRP to be used as a structural material (Passos et al., 2021).

The application of FRPs for the reinforcement of timber structures has proven its effectiveness in increasing the load-bearing capacity and, in some cases, the rigidity of structural members, thus providing cost-effective and competitive alternatives in both new design and retrofitting existing historic buildings (Saad and Lengyel, 2022). Among all FRP products, basalt fiber reinforced polymer (BFRP), carbon fiber-reinforced polymer, unidirectional glass fiber-reinforced polymer (GFRP), and aramid fiber-reinforced polymer, especially E-Glass fibers, seem to be the most effective in reinforcing wooden beams due to their low cost and favorable mechanical properties (Bywalski et al., 2020). BFRP has a higher strength and modulus, a similar cost, and more chemical stability compared to E-glass FRP (GFRP) (Wu et al., 2009). Basalt-based materials are environmentally friendly and non-hazardous. The current production technology for continuous basalt fibers is very similar to the technology used in the production of E-glass. The main difference is that E-glass is made from a complex pile of material, while the basalt filament is made from smelting basalt rock without any other additives, resulting in a cost-effective one. Their specific mechanical properties are comparable to or better than those of E-glass (Fiore et al., 2011). As an innovative material, basalt fiber reinforced polymer has the advantages of extremely good modulus and high strength (Wu et al., 2009; Wei et al., 2011; Fiore et al., 2011; Borhan, 2012; Wang et al., 2013). Based on the ultimate stress obtained from monotonic tensile tests, it is explained that basalt fiber fabrics have higher elongation resistance than both carbon-based and glass-based laminates (Palmieri et al., 2009; Wu et al., 2010; Dorigato and Pegoretti, 2012), basalt fibers have higher tensile strength than E-glass fibers (Wei et al., 2010; Carmisciano et al., 2011; Lopresto, 2011; Dorigato and Pegoretti, 2012) basalt fibers exhibit mechanical properties completely comparable to those of glass, with the elastic modulus of basalt being higher than that of glass fibers (Dorigato and Pegoretti, 2012). Various experimental studies show that reinforcing wooden structures provides an increase in load-bearing capacity, hardness and ductility over a wide range, most likely due to the organic structure of wood. Most studies show an increase in capacity of 20% to 50% (Gentile et al., 2002; Osmannezhad et al., 2015), a negligible increase in hardness (Amy et al., 2004; Fiorelli and Dias, 2003) or sometimes much higher (Gentile et al., 2002; Osmannezhad et al., 2015; Fiorelli et al., 2011). Goa et al. (2023) studied the mechanical properties and applications of glass fiber-reinforced polyurethane composites (GFRP) in communication pole line engineering. The results show that GFRP has high hardness, light weight, high strength and durability.

There are several studies using glass fiber-reinforced polymers and basalt fiber-reinforced polymers as reinforcement reinforcement for wood beams (Yusof and Saleh 2010; Fiorelli et al., 2011; Alhayek et al., 2012; Alshurafa et al., 2012; Morales-Conde et al., 2015; Osmannezhad et al., 2015: O'Ceallaigh et al., 2019; Wang et al., 2019; Bywalski et al., 2020; Balmori et al., 2020; Balmori et al., 2021; Karaman, 2021; Camargo et al., 2023; Ezika et al., 2023; Shekarchi et al., 2023).

When the studies related to the bending moment capacity of L-type doweled joints with reinforced the BFRPWF and the GFRPWF are examined in the literature review, However, it has been seen that studies on the the bending moment capacity of L-type two-pin dowel joints with reinforced investigate that are not applied and it is considered that there is a deficiency in the literature and at the same time the study to be carried out on this subject will be original and contribute to the literature. The aim of study was to investigate that the effects of wooden dowel species and the BFRPWF and GFRPWF on the bending moment resistance of the L-type doweled joints.

2. MATERIAL AND METHOD

For the study, the beech wood (*Fagus orientalis* Lipsky), widely employed in the furniture sector, was chosen as the wooden material (Figure 1e). Wood species used in the production of dowels are Scots pine (*Pinus sylvestris* Lipsky) (Figure 1h), beech (*Fagus orientalis* Lipsky) (Figure 1f), oak (*Quercus petrea* Lieble) (Figure 1g), and chestnut (*Castanea sativa* Mill) (Figure 1ı) . The selection of wood materials were conducted randomly from timber merchants located in Siteler-Ankara Turkey. Some physical and mechanical properties of wood materials are given Table 1.

Table 1. Some physical and mechanical properties of wood species used in the study (Bozkurt and Erdin, 2000).

Some physical and mechanical properties	Wooden dowel species			
	Beech	Sessile oak	Scots pine	Chestnut
Air-dry density (D_{12}) (g/cm^3)	0.66	0.69	0.52	0.56
Tension strength (MPa)	135	90	104	135
Compression strength (MPa)	62	60	55	50
Bending strength (MPa)	105	94	87	77
Modulus of elasticity (MPa)	16000	12300	12000	9000
Shear strength (Mpa)	8	11	10	8

The GFRPW and BFRPWF for 200 gr/m^2 plain materials used in the study was obtained by Dost Chemical Industry Raw Material Industry and Trading Company (Turkey, Istanbul) (Figure 1c and d). Some physical and mechanical properties of the BFRPWF and GFRPWF are shown in Table 2.

Table 2. Some physical and mechanical properties of the BFRPWF and GFRPWF (Valentino et al., 2014; Dong, 2019).

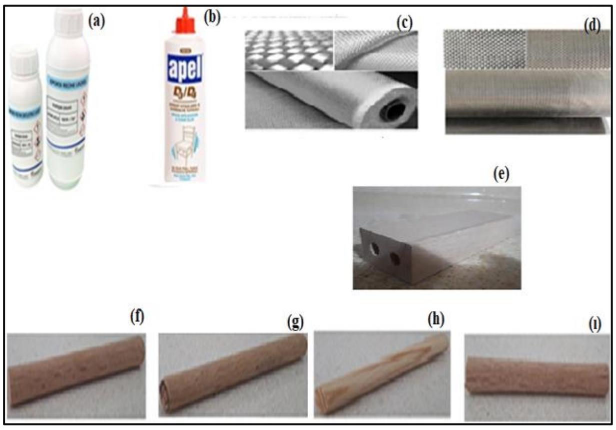
Property	FRPs	
	BFRPWF	GFRPWF
Density (g/cm^3)	2.8	2.58
Tensile strength (GPa)	2.80	3.45
Shear modulus (GPa)	21.7	30
Elastic modulus (GPa)	89	72
Elangation at break (%)	3.15	4.7

The FRPs were fastened with epoxy adhesive and hardener. The type of epoxy resin used in the matrix material was MGS L285 resin and hardener was MGS H285 (Dost Chemical Industry Raw Material Industry and Trading Co., Istanbul Türkiye (Figure 1a). The polyurethane adhesive (PUR) used in this the study was obtained by Beta Chemical Industrial Industry and Trade Company (Turkey, Istanbul) (Figure 1b). The technical parameters of the adhesives are given in Table 3.

Table 3. Technical data and characteristics of the adhesives.

Technical Data	Polyvinyl acetate (PVAc-D3/D4)	Epoxy (L285 Resin+ H285 Hardener)
Viscosity (mPas)	19000±5000	600 - 900
Working time (min)	35-40 at 21 °C	45-240 at 25 °C
Density (g/cm^3)	1.055±3 at 21 °C	1.21 at 25 °C
Solids content (%)	51±2	-
pH	2.5-3.5	-
Main agent/Hardener Ratio (w/w)	100/5	100/50

Figure 1. Materials used in experiments. (a) Epoxy adhesive. (b) Polyvinyl acetate (PVAc-D3/D4) adhesive. (c) GFRPWF. (d) BFRPWF. (e) Beech wood. (f) Beech dowel. (g) Oak dowel. (h) Scots pine dowel, and (ı) Chestnut dowel.



Preparation of test specimens

The wood materials were kept in the air conditioning room at 20±2°C and 65±3% relative humidity until their weight stabilized (TS 2470, 1976). Then, 1000x11x11 mm pieces were cut from beech sapwood, oak sapwood, chestnut sapwood and scotch pine sapwood for the dowel, and dowels with a diameter of 8 mm were produced from these pieces using a dowel machine. A diagram of the tested two-pin dowel joints is shown in Figure 2. Joint specimens were constructed of beech wood. The specimens consisted of two structrual parts, namely, a rail member anda post member. The rail part measured 150 mm long 50 mm width 25 mm thick, whereas the post member measured 125 mm long 50 mm width 25 mm thick. The dowels with a diameter of 8 mm and a length of 50 mm were used as the joining elements. The members were jointed to each other with 2 pieces of 8 mm diameter and 40 mm length dowels with the PVAc-D3/D4 adhesive. 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. The adhesive was spread over the dowel surfaces and dowel holes with approximately 200 g/m^2 calculation. In all of the samples, a piece of wax paper was included between the two members to prevent any possibility of the members adhesion. Then, areas where the BFRPWF and GFRPWF were to be placed were bonded with an average of 200 ± 10 gr/m² with a brush with a blend of epoxy adhesive and hardener. Joint instances were left to dry for two days.

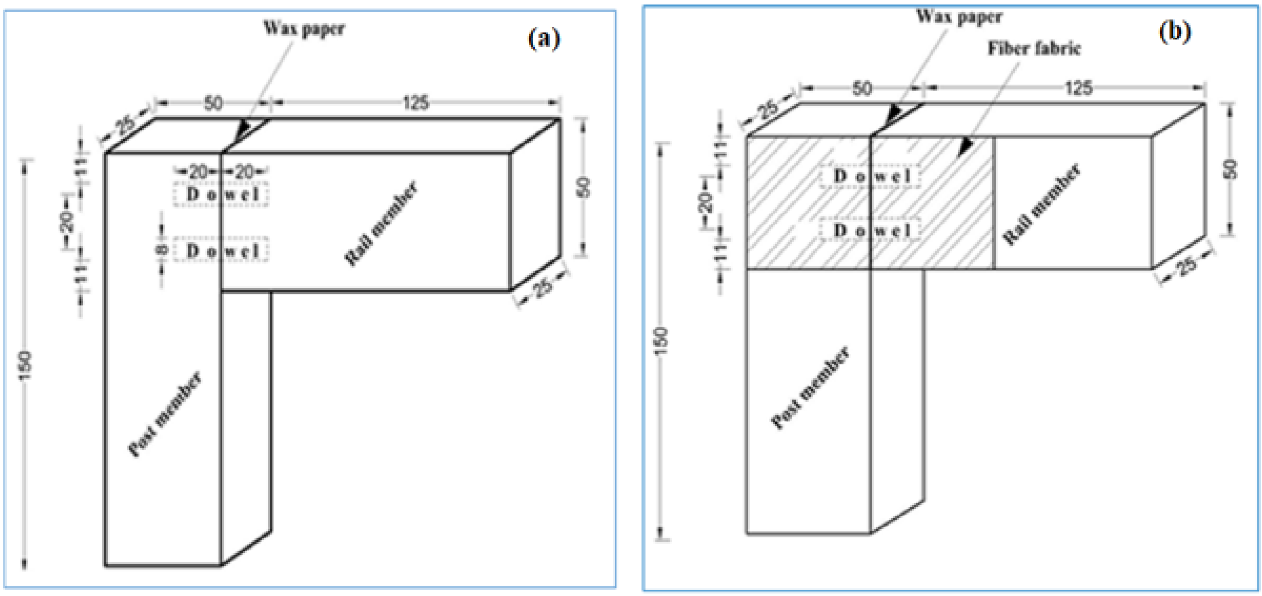


Figure 2. General configuration of L type dowel joints (dimensions in mm). (a) Unreinforced and (b) Reinforced with FRP.

According to this, four wooden dowel species, and two fiber woven fabrics (BFRPWF, GFRPWF, and control), and 5 samples of each material (4 x 3 x 5) were the variables, totally a number of 60 samples were constructed in this research. Prior to testing, all of the specimens obtained were conditioned at 20 °C ± 2 °C and 65 % ± 5 % percent relative humidity so that they could reach the equilibrium moisture content.

Test method

All of the bending tests were carried out on a 50 kN capacity universal testing machine (Shimadzu Autograph AG-IS, Sydney, Australia) in the laboratory of Karabuk University Sefik Dizdar Safranbolu Vocational High School. Figure 3 shows the set up for bending tests. A concentrated load was applied to the rail of each specimen at a point 100 mm from the front edge of the post, i.e., the moment arm was 100 mm. The loading speed was 8 mm/min. Loading was continued until breakage or separation occurred in the specimens. The loads carried by joints were recorded in newtons (N). The loads were then converted to corresponding bending moment values by means of the expression. The resistance of the joints (modulus of rupture) to bending forces was calculated using the following Eq. (1)

$$M = F \times L \quad (1)$$

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

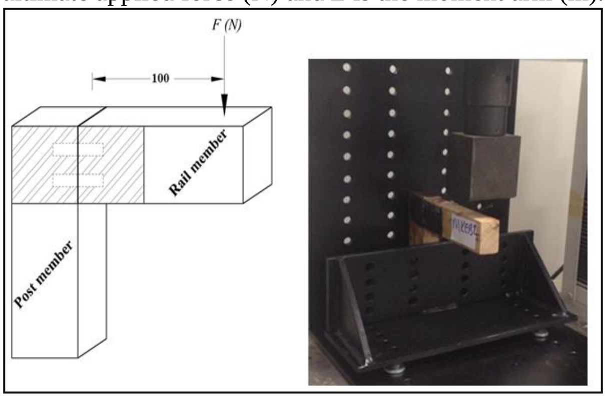


Figure 3. Way of support and loading the specimens of the L type dowel corner joints.

Statistical analyses

A two way analysis of variance (ANOVA) was made in wood L type corner joints in order to determine the effects of wooden dowel species, and FRP types. In case of mutual interactions of sources of variance, significant at α = 0.05, Tukey test was used to identify which factors made the difference.

3. RESULTS AND DISCUSSION

Mean values of the bending moment capacity of the tested L-type dowel joints with their standard deviation and coefficients of variation are shown in the following Table 4.

Table 4. Bending moment resistance (N.mm) of L-type doweled joints (N.m).

Wood*en* Dowel Species	FRP Types	Mean	SD	COV (%)
Beech	Control (Unreinforced)	34.37	3.84	11.19
	GFRPWF	43.87	4.91	11.19
	BFRPWF	54.06	6.50	12.01
Chestnut	Control (Unreinforced)	29.28	2.51	8.58
	GFRPWF	41.28	5.73	13.89
	BFRPWF	51.87	8.37	16.13
Oak	Control (Unreinforced)	41.03	5.37	13.08
	GFRPWF	50.69	9.63	19.00
	BFRPWF	71.00	7.33	10.32
Scots pine	Control (Unreinforced)	23.56	4.18	17.74
	GFRPWF	31.94	3.77	11.81
	BFRPWF	45.56	7.49	7.70

SD: Standart deviation COV (%): Coefficient of variation.

According to multiple comparisons on the bending moment capacity, the highest bending moment resistance value was obtained from jointed with an oak dowel and reinforced with the BFRPWF (71 N.m), while the lowest value was acquired in joint with Scots pine dowel and unreinforced (control) (23.56 N.m).

The results of the multi-way ANOVA analysis of the wooden dowel species and reinforced fiber woven fabrics on the bending moment resistance of the L-type, two pin dowel joints under the compression load were given in the Table 5.

Table 5. Summary of the ANOVA results for bending moment resistance.

Source	df	Sum of Squares	Mean Square	F	P
Wooden dowel species (A)	3	3283.128	1094.376	28.972	.000
FRP types (B)	2	5599.991	2799.996	74.125	.000
A×B	6	220.176	36.696	.971	.455
Error	48	1813.145	37.774		
Total	60	122945.364			
Corrected Total	59	10916.439			

R Squared = .834 (Adjusted R Squared = ,796) df: Degrees of Freedom.

According to the analysis of variance as presented in Table 3, the effects of the main factors including, the wooden dowel species (A) and the FRP (B), were found to be statistically significant at the level of 0.05. Interactions of the wooden dowel species and the FRP (A×B) were not found to be statistically significant at the level of 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 6.

Table 6. The results from the Tukey's test for independent effects of test variables (N.m)

Source		Bending moment resistance	HG
Wooden dowel species	Oak	54.24	A
	Beech	44.10	B
	Chestnut	40.81	B
	Scots pine	33.69	C
FRP types	BFRPWF	55.62	A
	GFRPWF	41.95	B
	Control	32.06	C

HG: Homogeneity groups,

For the wooden dowel species, the oak dowel showed significantly higher the bending moment resistance value than other dowels (Table 6), The bending moment resistance value of oak was approximately 23%, 33% and 61% higher than for joints constructed with beech, chestnut, and Scots 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.

According to FRP types, the highest bending moment resistance value were obtained in the BFRPWF (55.62 N.m), and the lowest was in control samples (32.06 N.m), The mean bending moment resistance of joints with the BFRPWF was 33 % and 73 % higher than joints with GFRP, and not reinforced joints (control), respectively.

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 L-type doweled joints construction with Beech 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 and Chestnut dowel test samples (see Figure 4a, 4b),the Scots pine and beech dowel samples followed respectively (see Figure 4d, 4c).

According to the reinforced joints, GFRPWF 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 Chestnut dowel+GFRPWF, cracks occurred on the inner face of the face members (Figure 4e). The deformations of dowel joints the reinforced with GFRPWF strengthened are than not reinforced samples. It is seen that the deformation of the dowel joints reinforced with GFRPWF is less than the samples in reinforcement.

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 the BFRPWF, failures have occured on the outer face of the basalt woven fiber fabric, In all of the samples the beech dowel joints reinforced with the BFRPWF (Figure 4i), the failures are almost identical, it is seen that the failures occurred as a result of cracking at the junction of the middle of the BFRPWF are more in the beech dowel (Figure 4i), and the Scots pine dowel (Figure 4k) samples.

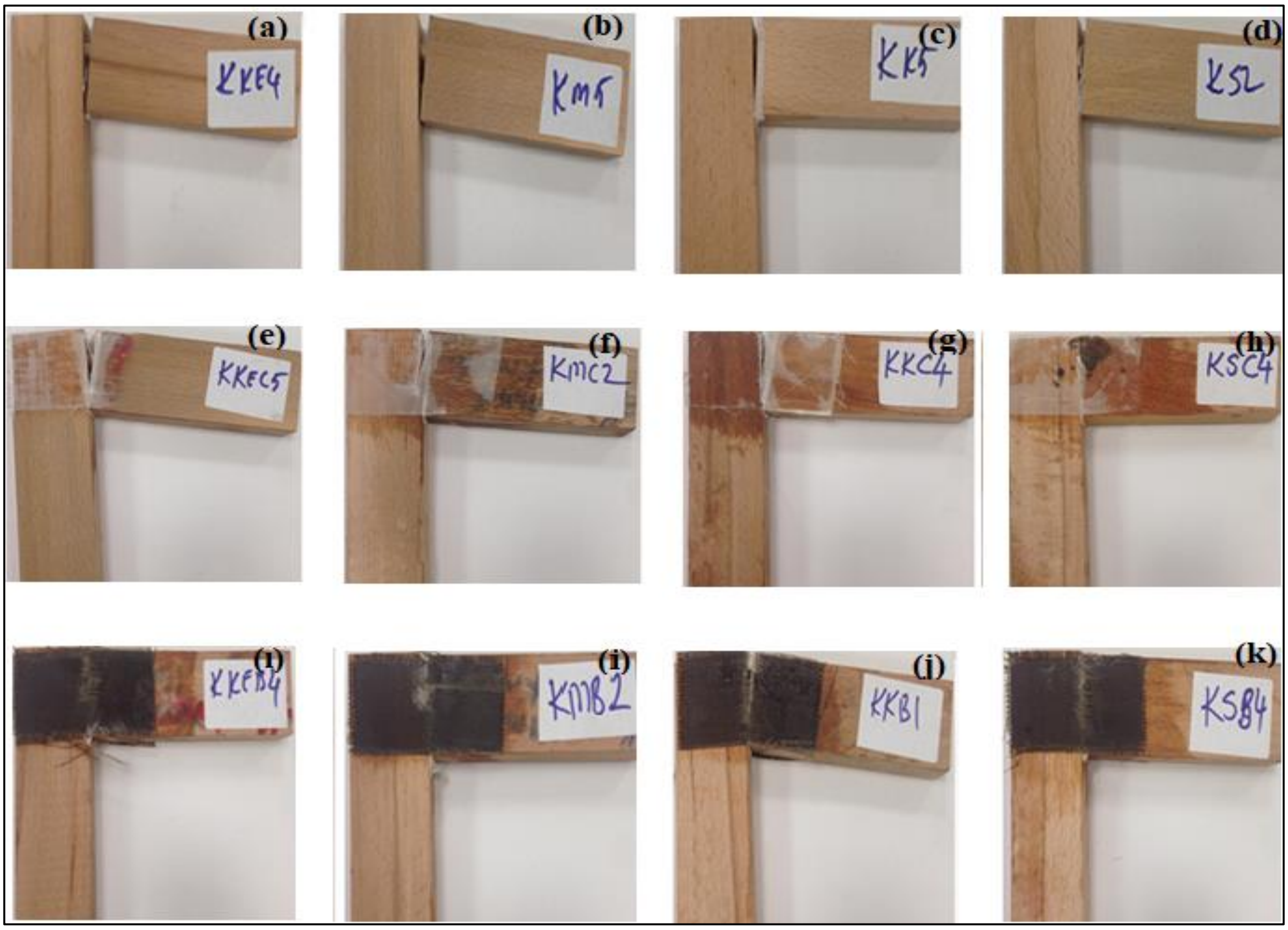


Figure 4. Failure modes of the experimental samples under bending strength test. (a) Chestnut dowel joints. (b) Oak dowel joints. (c) Beech dowel joints. (d) Scots pine dowel joints. (e) Chestnut dowel + GFRPWF joints. (f) Oak dowel + GFRPWF joints. (g) Beech dowel + GFRPWF joints. (h) Scots pine dowel + GFRPWF joints. (ı) Chestnut dowel + BFRPWF joints. (i) Oak dowel + BFRPWF joints. (j) Beech dowel + BFRPWF joints, and (k) Scots pine dowel + BFRPWF joints.

4. DISCUSSION AND CONCLUSIONS

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 L-type doweled joints constructed four wooden dowel species and reinforced with the BFRPWF and GFRPWF was investigated. Experimental results indicated that traditional glued Oak dowel joints yielded the highest bending moment resistance among beech dowel, Chestnut dowel and Scots pine dowel joints. Scots 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 the GFRPWF and BFRPWF joints, respectively) were 31 % and 74 % higher than unreinforced joints.

Fiorelli and Alves (2002) explained that the increase in the rigidity of beams reinforced with GFRP is between 15% and 30%. Speranzini et al. (2010) examined solid timber beams externally reinforced with carbon, glass, basalt, hemp and flax FRP under a four-point bend test (the increase in flexural strength was 24.6% and 23.2% for glass and basalt, respectively). Yusof and Saleh (2010) reinforced the beams with GFRP rods placed in the slots on the underside. In this case, the tested bearing resistance increase was between 20% and 30%, and the hardness increase was between 24% and 60%. Borri et al. (2013) investigated low-grade and high-grade timber beams reinforced with linen and basalt FRP. The results showed a 38.6% and 65.8% increase in the bending strength of low-grade timber beams reinforced with FFRP and BFRP, respectively. In addition, strength increases were 29.2% and 25.9%, respectively, and maximum mid-deflection increases were 9.1% and 14.5%, respectively. Monaldoa et al. (2019) explained that beams reinforced with BFRP have a bending ultimate load higher of by about 20 % than the case of GFRP. Shekarchi et al. (2020) performed a series of tests on a wooden beam that was unreinforced and reinforced with GFRP. The test results showed that the bending performance of glulam is effectively enhanced by the binding of GFRP; Here, the bending stiffness, ductility, and energy absorption of reinforced beams increased by up to 59%, 79%, and 209%, respectively, compared to unreinforced beams.

Researchers could be provide a range of optimum values, for the parameters (four different wooden dowel species, FRP 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.

Ethics Committee Approval
N/A

Peer-review
Externally peer-reviewed.

Author Contributions

The manuscript was written by the corresponding author. The author declares that the materials and methods used in this study do not require ethical committee approval or legal-specific permission.

Conflict of Interest
The authors have no conflicts of interest to declare.

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