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THE INFLUENCE OF THE NUMBER AND POSITION OF DOWELS ON THE BENDING MOMENT CAPACITY OF HEAT-TREATED WOOD DOWEL JOINTS

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Abstract: *In this work, the influence of the number of dowels and the option to place the dowels in the cross section of part on the bending moment capacity of heat-treated wood dowel joints was analysed. The joints, which were made of heat-treated ash, were tested by means of a universal testing machine. The ultimate failure load and the moment arms were used to figure out the bending moment capacity of the joints loaded in compression or in tension. The number of dowels affected the tensile strength of the L-shaped heat-treated wood joints. The modality to place the dowels in the cross section of rail, namely, in collinearity or in a triangular shape, did not significantly affect the strength of the heat-treated wood dowel joints.*

Key words: *wood joints, heat-treated wood, dowels, bending moment capacity.*

1. Introduction

Choosing the right wood joint for a furniture structure is a difficult task because there are a lot of possible constructive solutions [16]. One constructive solution that could be applied to assemble the main parts of a furniture structure is the L-shaped dowel joint (Figure 1) [6], [12].

Many factors could affect the strength of the L-shaped dowel joint, such as dowel diameter, type of dowel, dowel length, depth of dowel embedment, number of dowels, distance between dowels, position to place the dowels, adhesive

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type, wood species, etc. One could find more information in the literature regarding the factors that affect the strength of the L-shaped dowel joint [1, 2], [6], [10], [12], [14], [16].

The majority of published studies deal with factors which affect the strength of L-shaped dowel joints that were made of untreated wood [2], [6], [12], [14], [16]. There are few studies that present the influence of the factors which affect the strength of heat-treated wood dowel joints. These studies are about the effect of heat treatment on the mechanical properties of dowel joints [11], the influence of wood species and adhesive on the strength of dowel joints [5], the influence of dowel length, dowel spacing, depth of dowel embedment, dowel diameter and adhesive consumption on the bending moment capacity of heat-treated wood dowel joints [7, 8], [13]. However, none of these studies have analysed the influence of the number of dowels and the dowel position on the strength of heat-treated wood dowel joints. Therefore, the objective of this paper is to analyse the influence of the number of dowels and the options to place the dowels in the cross section of rail on the bending moment capacity of joints loaded in compression or in tension.

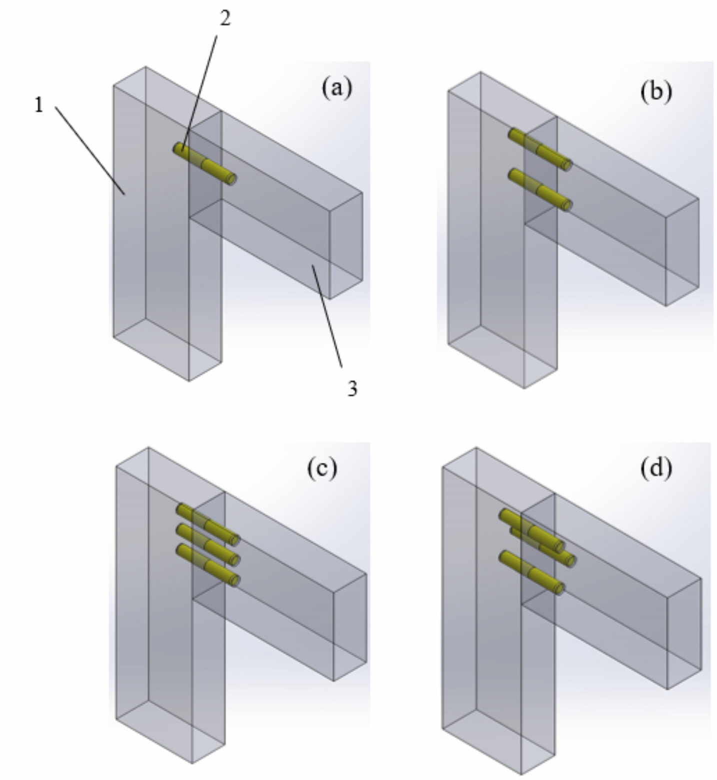

Fig. 1. *The 3D view of the analysed L – shaped dowel joints;*
a – the parts of the joint were assembled by using one dowel; b – the parts of the joint were assembled by using two dowels; c – the parts of the joint were assembled by using three dowels that were placed in a collinear shape; d – the parts of the joint were assembled by using three dowels that were placed in a triangular shape; 1 – leg; 2 – dowels; 3 – rail

2. Material and Methods
2.1. Material

The joints were made of heat-treated ash (*Fraxinus excelsior* L.). The dimension of the leg was 200 x 70 x 30 mm and the dimension of the rail was 130 x 70 x 30 mm. The moisture content of the material used to carry out the joints was about 5%. The density of the material was 618 kg/m^3.

The joints were assembled by means of multi-grove dowel pins and D4 Polyvinyl acetate adhesive (Kleiberit 303; Kleiberit, Weingarten, Germany). More information about the material, the adhesive, and the process of assembling joints can be found in the literature [8], [13].

2.2. Method

The experimental setup applied in this research is presented in Table 1. The first analysed scenario consisted in placing one dowel in the middle of the cross section of rail (Figure 1a) and changing the dowel diameter. The analysed diameters of the dowels were 6, 8, and 10 mm. Even though this constructive solution is not used in wood joinery practice, this setup was needed to quantify the strength increase of the dowel joint when the number of dowels was increased from one to two. The second scenario was to place two dowels in the cross section of the part`s joint (Figure 1b). The distance between the two dowels was 32 mm. The third and fourth scenarios consisted in placing the dowels in a collinear shape (Figure 1c) and in triangular shape (Figure 1d). For the third and fourth scenarios the distance between dowels was 16 mm. The length of the dowels was 50 mm. The depth of dowel penetration in the rail of the joint was 0.55 from its length [7]. Each configuration (Figure 1) was replicated six times.

Table 1

The factors used in this study

Factor	Value
Number of dowels	1
	2
	3
Position of dowels	The dowels were placed in a collinear shape
	The dowels were placed in a triangular shape

The responses were the bending moment capacity of the joints loaded in tension or in compression (Figure 2). The bending moment capacity of the joints was revealed through Equation (1) for the compression test and Equation (2) for the tension test [4], [8, 9], [13].

$$M_c = F \times L_c \quad (1)$$

$$M_t = \frac{F}{2 \cdot L_t} \quad (2)$$

where

M_c is the bending moment of joints subjected to compression (Nm);

M_t – the bending moment of joints loaded in tension;

F – the ultimate failure load (N);

L_c – the compression moment arm (0.042m);

L_t – the tension moment arm (0.092m).

The ultimate failure load was figured out by testing the joints loaded in compression or in tension on a universal testing machine (Zwick Roell, Zwick GmbH & Co. KG, Ulm, Germany). More information about the calculus of the bending moment capacity and the testing methodology can be found in the literature [3, 4], [9], 15].

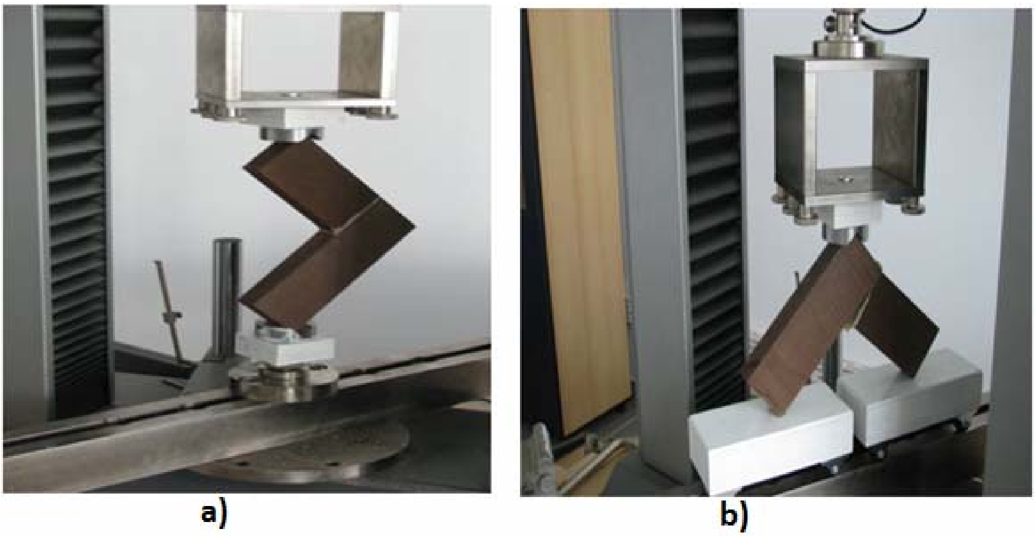

Fig. 2. *The testing of joints loaded in compression (a) or in tension (b)*

3. Results

The number of dowels significantly influenced the bending moment capacity of the joints loaded in compression or in tension when the dowel diameter was equal to 6 mm (p-value<0.05). The mean and standard deviation are presented in Tables 2 and 3.

In the case of dowels of 6mm diameter, one could observe an important increase in compressive strength (about 50%) and tensile strength (about 34%) when the number of dowels was increased from one to two (Figure 3). By increasing the number of dowels from two to three, the tensile strength of the analysed joints increased by 43%. Regarding the compressive strength, one could observe that there was a small difference, namely 5% (Figure 3).

Even though visually a difference of 20% in the tensile strength and 5% in the compressive strength of the wood joints can be observed in Figure 3, when the modality to place the dowels in the cross section of a rail were changed from collinear to triangular shape, there was not a significant difference between the analysed groups (p-value ≥ 0.05) (Tables 2 and 3).

On the other hand, the applied statistical test (One-way ANOVA) showed that the number of dowels did not affect the compressive strength of the analysed heat-treated wood joints when the diameter was adjusted to either 8 or 10 mm (p-value ≥ 0.05) (Tables 4 and 6).

Table 2

Bending moment capacity of L-shaped wood joints with dowels of 6 mm loaded in compression

	Number of dowels			
Specimen #	One	Two	Three – collinear shape	Three – triangular shape
1	44	48	84	88
2	42	85	93	80
3	47	96	79	84
4	73	97	47	79
5	45	42	75	71
6	51	82	97	95
Mean	**50**	**75**	**79**	**83**
Standard deviation	**11**	**24**	**18**	**8**
F - critical	**3.68**			**4.96**
F	**4.34**			**0.18**
p-value	**0.03**			**0.677**
α	**0.05**			

Table 3

Bending moment capacity of L-shaped wood joints with dowels of 6 mm loaded in tension

	Number of dowels			
Specimen #	One	Two	Three – collinear shape	Three – triangular shape
1	65.32	103.96	133.86	115.92
2	108.1	133.86	176.18	135.24
3	98.44	135.7	186.3	130.18
4	63.94	86.02	136.16	144.44
5	69.92	95.22	149.04	130.64
6	78.66	100.74	155.94	129.26
Mean	**81**	**109**	**156**	**131**
Standard deviation	**18**	**21**	**21**	**9**
F - critical	**3.68**			**4.96**
F	**21.44**			**7.14**
p-value	**<0.01**			**0.02**
α	**0.05**			

However, the number of dowels affected the tensile strength of the heat-treated wood joints when the dowel diameter was equal to 8 or 10 mm (p-value<0.05) (Tables 5 and 7). When the number of dowels was increased from one to two (Figures 4 and 5), the tensile strength increased by about 34% in the case of the dowels with diameter of 8 mm and by 43% in the case of the dowels with diameter of 10 mm. By changing the number of dowels from two to three there was an increase in tensile strength of 68% in the case of the dowels of 8 mm and 24% in the case of the dowels of 10 mm (Figures 4 and 5).

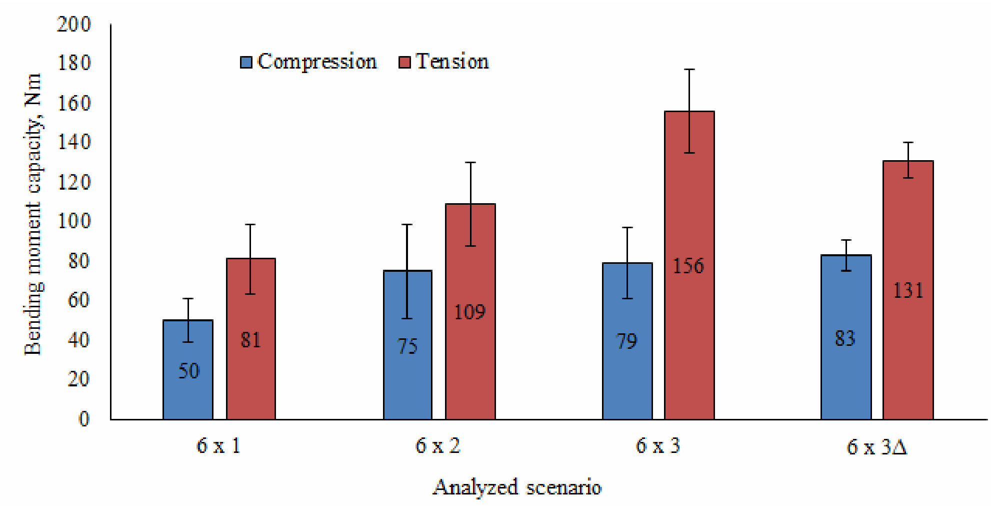

Fig. 3. *The bending moment capacity of L-shaped joints loaded in compression and in tension when the dowel diameter was equal to 6 mm*

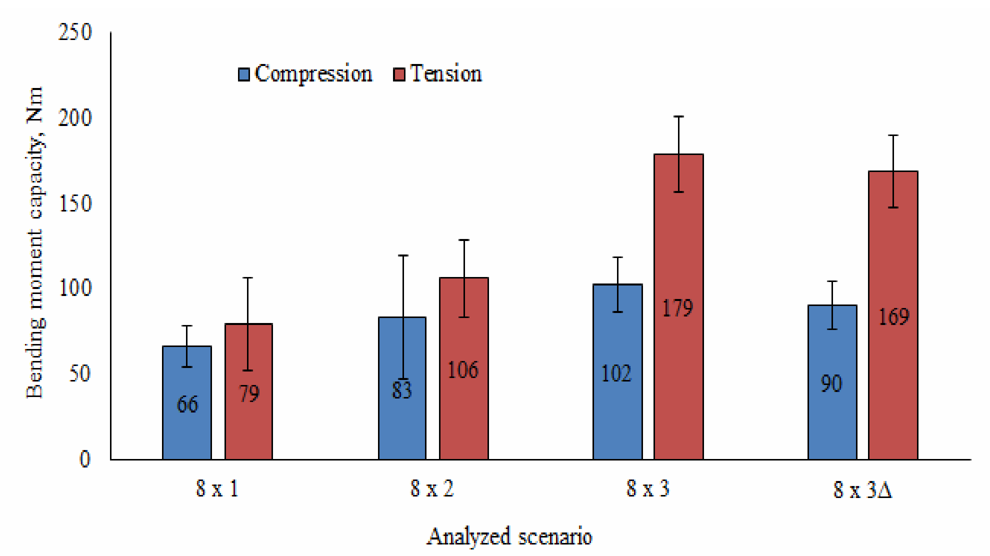

Fig. 4. *The bending moment capacity of L-shaped joints loaded in compression and in tension when the dowel diameter was equal to 8 mm*

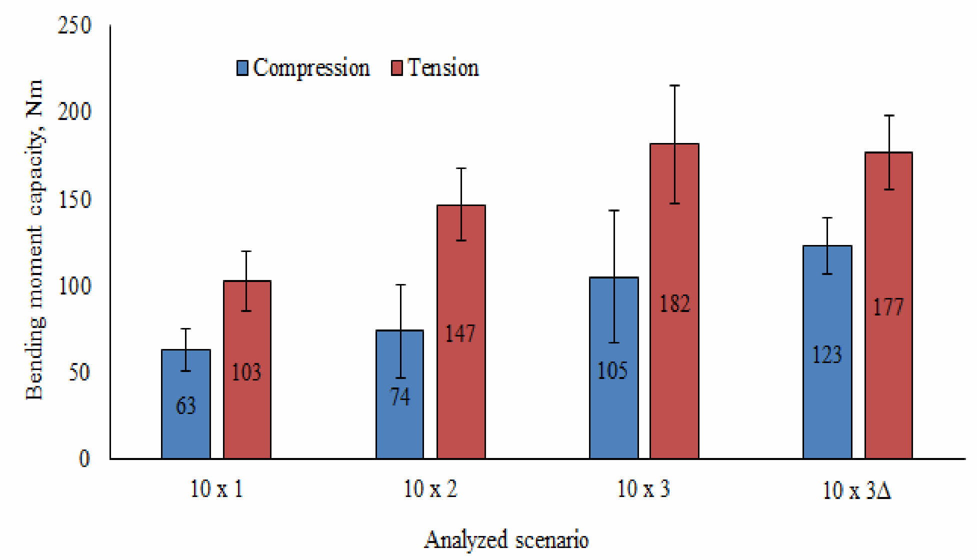

Fig. 5. *The bending moment capacity of L-shaped joints loaded in compression and in tension when the dowel diameter was equal to 10 mm*

Even though one could observe in Figures 5 and 6 a difference of 20% in the tensile strength of the wood joints and a 5% difference in the compressive strength when the option to place three dowels on the cross section of rail was changed from collinear to triangular shape, there was not a significant difference (p-value ≥ 0.05) (Tables 4 - 7).

Table 4

Bending moment capacity of L-shaped wood joints with dowels of 8 mm loaded in compression

	Number of dowels			
Specimen #	One	Two	Three – collinear shape	Three – triangular shape
1	79	57	125	80
2	50	85	100	109
3	52	138	93	105
4	68	32	115	82
5	79	87	97	84
6	66	101	82	78
Mean	**66**	**83**	**102**	**90**
Standard deviation	**12**	**36**	**16**	**14**
F - critical	**3.68**			**4.96**
F	**3.46**			**2.06**
p-value	**0.05**			**0.18**
α	**0.05**			

Table 5

Bending moment capacity of L-shaped wood joints with dowels of 8 mm loaded in tension

	Number of dowels			
Specimen #	One	Two	Three – collinear shape	Three – triangular shape
1	63	84	163	152
2	74	125	147	164
3	123	85	211	139
4	56	114	184	187
5	98	139	175	196
6	59	89	193	175
Mean	**79**	**106**	**179**	**169**
Standard deviation	**27**	**23**	**22**	**21**
F - critical	**3.68**			**4.96**
F	**27.48**			**0.67**
p-value	**<0.01**			**0.43**
α	**0.05**			

Table 6

Bending moment capacity of L-shaped wood joints with dowels of 10 mm loaded in compression

	Number of dowels			
Specimen #	One	Two	Three – collinear shape	Three – triangular shape
1	60	113	79	136
2	84	40	154	131
3	52	72	74	122
4	68	98	65	135
5	61	67	146	93
6	54	53	113	124
Mean	**63**	**74**	**105**	**123**
Standard deviation	**12**	**27**	**38**	**16**
F - critical	**3.68**			**4.96**
F	**3.63**			**1.17**
p-value	**0.05**			**0.30**
α	**0.05**			

Table 7

Bending moment capacity of L-shaped wood joints with dowels of 10 mm loaded in tension

Specimen #	Number of dowels			
	One	Two	Three – collinear shape	Three – triangular shape
1	127	121	166	146
2	103	127	197	161
3	108	143	159	176
4	95	160	213	201
5	75	178	133	200
6	109	151	222	176
Mean	**103**	**147**	**182**	**177**
Standard deviation	**17**	**21**	**34**	**21**
F - critical	**3.68**			**4.96**
F	**14.55**			**1.17**
p-value	**<0.01**			**0.30**
α	**0.05**			

4. Conclusion

The influence of the number and position of dowels on the bending moment capacity of L-shaped heat-treated wood dowel joints loaded in compression or in tension was analysed in this research. Based on the obtained results, the following conclusions could be drawn:

- The number of dowels significantly influenced the bending moment capacity of the joints loaded in compression or in tension when the dowel diameter was equal to 6 mm;
- The number of dowels affected only the tensile strength of the heat-treated wood joints when the dowel diameter was equal to 8 and 10 mm;
- The modality to place the dowels in the cross section of rail, namely in a collinear or a triangular shape, did not significantly affect the strength of the heat-treated wood dowel joints.

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