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THE INFLUENCE OF THE FREEZING AND THAWING PROCESS ON THE BENDING MOMENT CAPACITY OF L-SHAPED HEAT-TREATED WOOD DOWEL JOINTS

Bogdan BEDELEAN[1] Răzvan COCIȘ[1]

Abstract: *In this work, the influence of the freezing and thawing process on the bending moment capacity of L-shaped heat-treated wood dowel joints is analysed. The parts of the joints were made of heat-treated ash (Fraxinus excelsior) wood. Half of the analysed joints were randomly divided in two groups. One group was frozen and thawed in a climatic chamber and the other group was kept in laboratory environmental conditions. The bending moment capacity was calculated by means of ultimate failure load, which was experimentally obtained. One-way analysis of variance (One-way ANOVA) was applied to figure out if there is a significant difference between the analysed groups. Based on the obtained results, it was concluded that the freezing and thawing process did not significantly affect the strength of the L-shaped heat-treated wood dowel joints.*

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

1. Introduction

Although heat treatment decreases the mechanical properties of wood, the request for furniture made of heat-treated wood is growing due to the fact that this kind of material offers better characteristics regarding dimensional stability and biological durability than untreated wood [12].

Outdoor furniture made of heat-treated wood can be assembled by using various types of joints such as mortise and tenon joint, dowel joint, biscuit joint, dovetail joint. Moreover, the parts of the joints can

[1] Department of Wood Processing and Wood Product Design, Faculty of Furniture Design and Wood Engineering, Transilvania University of Brasov, Universităţii no. 1, Brasov 500068, Romania;
Correspondence: Bogdan Bedelean; email: bedelean@unitbv.ro.

be assembled through metallic or plastic fasteners [7], [15], [18].

The quality of furniture joints can be determined based on rigidity and strength. Since the theoretical calculus is based on simplifying assumptions, experimental methods are recommended in the literature [4], [15]. The experimental method consists in loading the corner joint in compression or in tension, according to the procedure presented in Figure 1.

The bending moment capacity is calculated by means of equations (1) and (2), according to the literature recommendations [6], [11], [18]:

$$M_C = F \cdot L_C \quad (1)$$

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

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], which is experimentally determined;
- L_c - the compression moment arm;
- L_t - the tension moment arm.

Nowadays, one of the most used joints in the wood manufacturing process is the L-shaped dowel joint (Figure 1) [13]. The main advantage of this kind of joint consists in a low manufacturing cost and can be obtained fast and easily from a technological point of view [1], [7].

According to the literature [2–3], [7– 15], [19], many factors can affect the strength of L-shaped wood dowel joints, like dowel diameter, dowel length, depth of dowel embedment, number of dowels, distance between dowels, position of dowels, wood species, adhesive type, presence of defects in the parts of the joints, etc. However, there is a lack of studies regarding the influence of the freezing and thawing process on the strength of heat-treated wood dowel joints. This process can affect the mechanical properties of the joints due to the micro-cracks that occur in the cell wall structure during the freezing process and in the adhesive film as well [16–17].

Therefore, the aim of this paper is to investigate whether the micro-cracks that might occur during the freezing and thawing process can affect the strength of heat-treated L-shaped wood dowel joints. The results of this research can be applied during the design phase of outdoor furniture made of heat-treated wood which will be exposed to a cold winter climate.

2. Materials and Methods

2.1. Materials

In this study, the parts of the joints were made of heat-treated ash (*Fraxinus excelsior* L.) wood. The dimension of the parts, which had a moisture content of about 5% and a density of 618 kg/m^3, was 200 x 70 x 30 mm in the case of the leg, and 100 x 70 x 30 mm in the case of the rail (Figure 1). The adhesive used in this work was D4 Polyvinyl acetate adhesive (Kleiberit 303; Kleiberit, Weingarten, Germany). The main properties of the adhesive used in this research are presented in Table 1. The temperature inside the room where the joints were assembled was about 20°C.

The parts of the joints were joined by means of multi-grove dowel pins which were made of beech wood. Prior to assembly, the parts were visually sorted to ensure that none of the parts have visible surface cracks.

Also, the parts were sorted in three groups based on the annual ring orientation (radial, semi-radial, and tangential). More information regarding the materials used in this work can be found in the literature [8], [14].

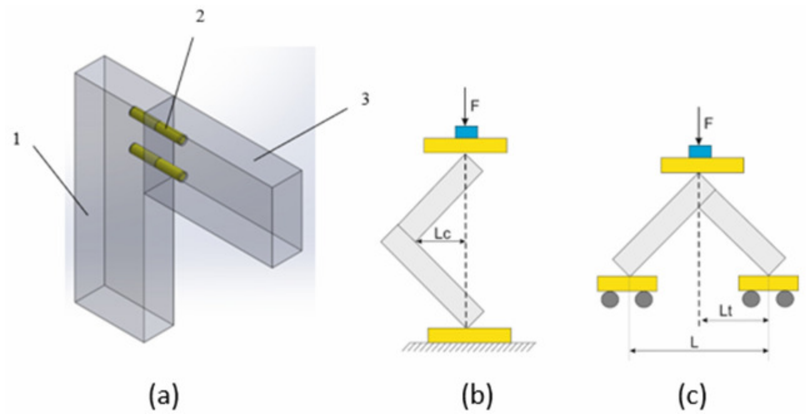

Fig. 1. *The analysed L-shaped dowel joint (a), the compression loading of a joint (b), and the tension loading of a joint (c). 1 – leg; 2 – dowels; 3 – rail*

The properties of the Kleiberit 303 adhesive Table 1

Density	1.10 g/cm^3
PH-value	3
Viscosity at 20°C	12,000 ± 2mPa·s
Open time at 20°C	6-10 minutes
Pot life	24h
Pressing time at 20°C	Minimum 15 minutes
Time to achieve final bond strength	7 days

In this work, 116 heat-treated wood dowel joints were manufactured. The dowel length was 50 mm and the dowel diameter was 8 mm. The depth of the dowel penetrations in the rail of the joint was 0.55 from its length [8]. An adhesive consumption of 350 g/m^2 was used to assemble the parts of the joints. The adhesive was sized by means of a 1ml syringe and applied by means of a rod made of glass (Figure 2). To avoid the adhesion of parts in the common contact areas, waxed paper was applied [5]. The parts of the joints were kept pressed until the next day (24h) by using wood clamps. Afterwards, the joints were kept in laboratory environmental conditions for several days.

2.2. Methods

Forty joints were made from parts with tangential orientation of annual rings; thirty-six joints were made from parts with radial orientation of annual rings, and forty joints were made from parts with semiradial orientation of annual rings. Half of the joints from each category (radial, tangential, and semi-radial) were randomly divided in two groups. One group was frozen and thawed in a FEUTRON type 3423-16 chamber, according to the schedule presented in Table 2. The total time of the freezing and thawing cycle was twenty days. The other group was kept in laboratory environmental conditions for the same amount of time. The evolution of the temperature and relative humidity of both environments, and the temperature of the joints is shown in Figures 3, 4, and 5. In the laboratory, the air and material parameters were measured using an AHLBORN capacitive sensor (FHA64E15) and an AHLBORN temperature resistive sensor (FPA32L0100). Inside the Feutron chamber the parameters were measured by means of in-built sensors.

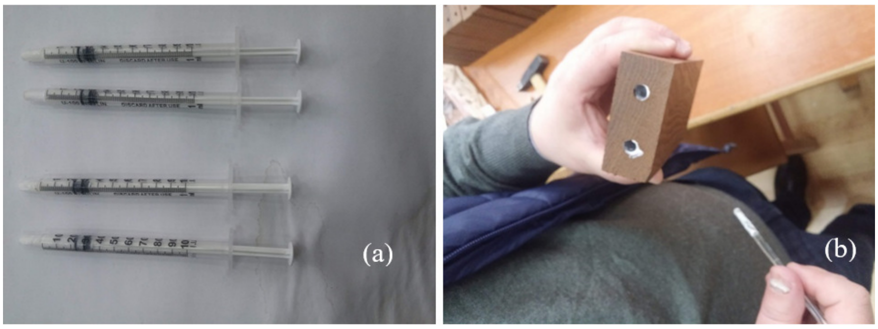

Fig. 2. *The approach used to size and apply the adhesive*

The freezing and thawing schedule applied in the Feutron chamber Table 2

# Day number	Temperature [°C]	# Day number	Temperature [°C]
1	15°C	11	-25°C
2	10°C	12	-25°C
3	5°C	13	-20°C
4	0°C	14	-15°C
5	-5°C	15	-10°C
6	-10°C	16	-5°C
7	-15°C	17	0°C
8	-20°C	18	5°C
9	-25°C	19	10°C
10	-25°C	20	15°C

Once the freezing and thawing cycle was finished, the joints that were inside the *Feutron* chamber and the joints that were kept in the laboratory environment were loaded in compression or in tension (Figure 6) to reveal the bending moment capacity. The tests were performed on a universal testing machine (Zwick Roell, Zwick, GmbH & Co. KG, Ulm, Germany). The bending moment capacity was calculated by means of equations (1) and (2). The compression moment arm (L_c) was equal to 0.042 m, and the tension moment arm (L_t) was 0.092 m.

One-way analysis of variance (One-way ANOVA) was applied to figure out if there is a significant difference between the analysed groups.

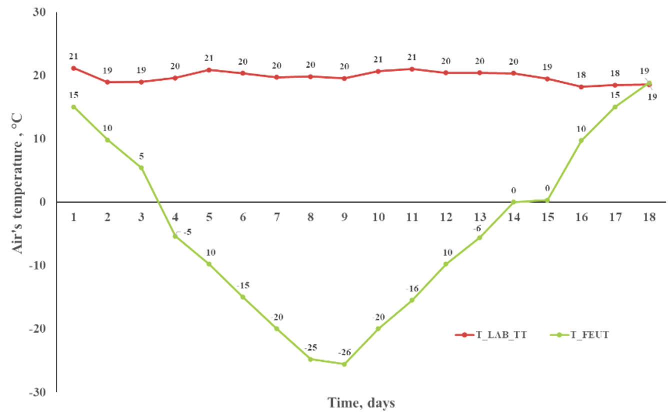

Fig. 3. *Evolution of air temperature inside the Feutron chamber and in the laboratory environment*

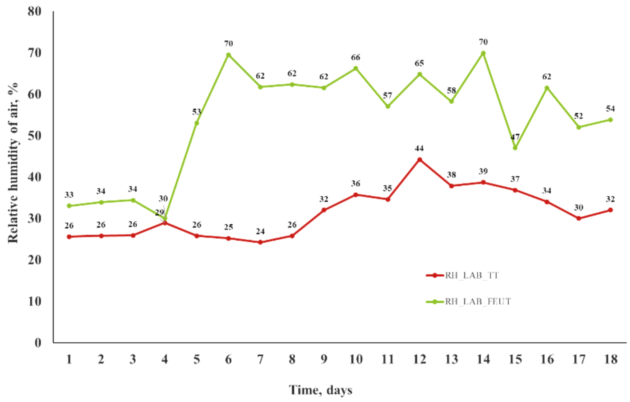

Fig. 4. *Evolution of relative humidity inside the Feutron chamber and in the laboratory environment*

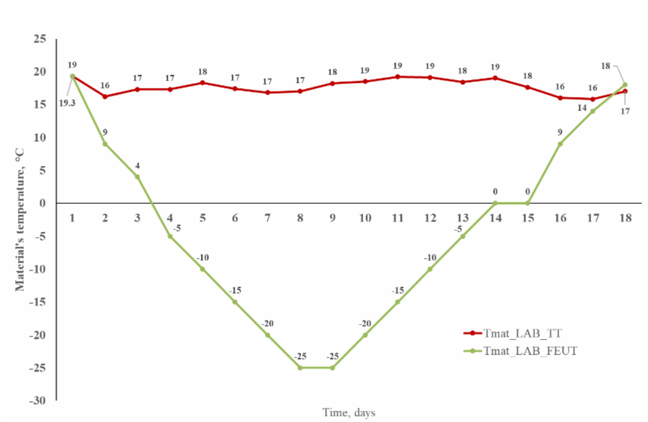

Fig. 5. *Evolution of material temperature inside the Feutron chamber and in the Laboratory environment*

Fig. 6. *The testing approach of the joints loaded in compression (a) or in tension (b)*

3. Results and Discussions

3.1. Compression Results

The bending moment capacity of the joints made of semiradial parts and loaded in compression was almost the same in both environmental conditions, namely, in the FEUTRON chamber and in the laboratory room (Table 3 and Figure 7a).

The joints loaded in compression which were made of tangential parts and were introduced in the FEUTRON chamber had a bending moment capacity higher by 18% than the joins that were kept in laboratory conditions (Table 4 and Figure 7a).

Table 3

The Bending moment capacity of L-shaped wood joints that were manufactured from semiradial parts and loaded in compression or in tension

Sample #	Compression [Nm]		Tension [Nm]	
	SRC LAB_FEUT[1]	SRC_LAB_TT[2]	SRC_LAB_FEUT[1]	SRC_LAB_TT[2]
1	99.12	61.74	138.46	119.14
2	40.992	58.8	64.40	98.44
3	75.18	66.78	142.14	182.16
4	54.18	62.58	107.64	116.38
5	45.36	89.88	124.66	85.56
6	70.98	37.08	128.34	100.28
7	60.48	52.50	138.46	80.96
8	66.36	60.06	104.88	88.78
9	47.46	101.64	172.50	143.98
10	77.28	57.96	186.76	115.46
Mean	**64**	**65**	**131**	**113**
Standard deviation	**18**	**18**	**35**	**31**
F-test	**0.02**		**1.46**	
F-critical	**4.41**		**4.41**	
p-value	**0.88**		**0.24**	
Significant level (α)	**0.05**			

1 - semiradial parts that were introduced in the FEUTRON chamber; 2- semiradial parts that were kept in laboratory environmental conditions

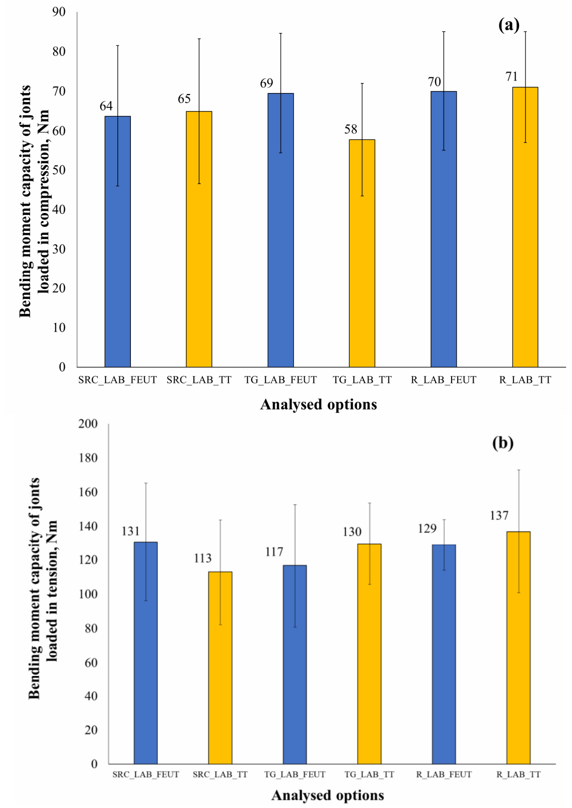

Fig. 7. *The bending moment capacity of L-shaped joints loaded in compression (a) and in tension (b): SRC_LAB_FEUT, TG_LAB_FEUT, R_LAB_FEUT – joints made of semiradial (SRC) / tangential (TG) / radial (R) parts that were introduced in the FEUTRON chamber; SRC_LAB_TT, TG_LAB_TT, R_LAB_TT – joints made of semiradial (SRC) / tangential (TG) / radial (R) parts that were kept in laboratory environmental conditions*

In the case of the joints that were manufactured from radial parts, one can observe from the data presented in Table 5 and Figure 7a that the bending moment capacity of the joints loaded in compression was roughly the same when the compression test was applied.

3.2. Tension Results

One can observe that the joints that were made of semiradial parts and were kept in the FEUTRON chamber have a higher strength (around 15%) than those which were placed in the laboratory environment (Table 3 and Figure 7b).

The bending moment capacity of the joints made of tangential parts that were kept in the laboratory environment had a strength higher by 11% than the joints that were introduced in the FEUTRON chamber (Table 4 and Figure 7b).

Table 4

The *bending moment capacity of L-shaped wood joints that were manufactured from tangential parts and loaded in compression or in tension*

Sample #	**Compression [Nm]**		**Tension [Nm]**	
	TG LAB_FEUT[1]	**TG_LAB_TT[2]**	**TG_LAB_FEUT[1]**	**TG_LAB_TT[2]**
1	45.36	63.00	194.12	129.26
2	62.16	38.26	140.30	156.40
3	73.92	60.48	111.32	115.46
4	80.22	63.84	118.68	116.84
5	79.80	66.78	135.24	128.80
6	63.84	74.34	112.24	118.68
7	88.20	63.00	74.06	117.76
8	89.88	60.90	67.16	119.60
9	54.60	60.06	118.68	107.64
10	56.70	26.58	96.60	186.76
Mean	**69**	**58**	**117**	**130**
Standard deviation	**15**	**14**	**36**	**24**
F-test	**3.19**		**0.88**	
F-critical	**4.41**		**4.41**	
p-value	**0.09**		**0.35**	
Significant level (α)	**0.05**			

1 –tangential parts that were introduced in the FEUTRON chamber; 2- tangential parts that were kept in laboratory environmental conditions

Table 5

The bending moment capacity of L-shaped wood joints that were manufactured from radial parts and loaded in compression or in tension

Sample #	**Compression [Nm]**		**Tension [Nm]**	
	R_LAB_FEUT[1]	**R_LAB_TT[2]**	**R_LAB_FEUT[1]**	**R_LAB_TT[2]**
1	87.78	100.38	120.06	128.80
2	75.60	68.88	116.38	130.18
3	71.40	66.36	114.08	155.48
4	94.08	75.60	149.04	126.04
5	69.72	73.50	146.74	104.88
6	46.62	63.42	135.70	223.56
7	69.72	55.44	116.38	139.38
8	60.90	81.06	143.98	110.40
9	57.54	55.86	118.22	113.62
Mean	70	71	129	137
Standard deviation	15	14	15	36
F-test	**0.01**		**0.37**	
F-critical	**4.49**		**4.49**	
p-value	**0.90**		**0.54**	
Significant level (α)	**0.05**			

1 –radial parts that were introduced in the FEUTRON chamber; 2- radial parts that were kept in laboratory environmental conditions

Moreover, it can be observed that the bending moment capacity of the joints made of radial parts which were frozen and thawed in the FEUTRON chamber is lower by 6% than the value obtained for the joints that were kept in laboratory conditions (Table 5 and Figure 7b).

By analysing the data presented in Tables 3, 4, and 5, one can observe that, from a statistical point of view, there is not a significant difference regarding the strength of the joints that were kept either in the FEUTRON chamber, or in the laboratory environment. The *p-value* was higher than the assumed significant level (α=0.05) in all the analysed options.

4. Conclusions

In this work, the influence of the freezing and thawing process on the bending moment capacity of heat-treated wood dowel joints loaded in compression or in tension was analysed. The parts of the joints were manufactured from boards with radial, semiradial, and tangential orientation of annual rings. A part of the joints was introduced in the Feutron chamber and the other was kept in a laboratory room. One-way analysis of variance showed that the freezing and thawing process does not have a significant effect on the strength of the analysed joints. One possible reason for this result could be the fact that during the freezing and thawing process, micro-fissures did not develop or those that occurred did not affect the strength of the joints.

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