EFFECT OF THE FINGER LENGTH ON BENDING STRENGTH PROPERTIES OF THE FINGER JOINTED STEAMED AND UNSTEAMED BEECH WOOD (*Fagus sylvatica*)

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ABSTRACT

Finger jointing has been in use in production for many years, yet it is only with the decline in resource quality that interest in it for furniture has increased. Beech wood is one of the most important species for the furniture production in Europe. It is used mainly as steamed as well as unsteamed wood as raw material in many furniture applications. In this work, the utilization of small dimensions steamed and unsteamed beech wood (*Fagus silvatica*) was studied for the manufacture of finger jointed furniture lumber. Particularly, it was investigated the effect of the two most common used finger lengths (4mm and 10mm) on static bending strength (modulus of rupture and modulus of elasticity) of the finger jointed beech wood that was connected across the grain with a polyvinyl-acetate based glue (D1, D2, D3 durability classes) (EN 204:2001). Modulus of rupture (MOR) of unsteamed wood joints ranged from 33.51 N/mm^2 to 82.24 N/mm^2, which corresponds to a percentage of 30.8% to 75.7% respectively, in relation to that of the control solid wood (108.71 N/mm^2), whereas, modulus of rupture (MOR) of steamed wood joints fluctuated from 34.9 N/mm^2 to 80.27 N/mm^2, which corresponds to a percentage of 32.7% to 75.1% respectively, in relation to that of the control solid wood (106.83 N/mm^2). In both, steamed and unsteamed wood the samples with a horizontal finger orientation showed slightly higher MOR values than that with a vertical orientation. It was also found that the MOE of all the unsteamed joints studied was not affected by finger jointing and ranged in the same level values of the control solid wood whereas, MOE of the steamed joints studied increased slightly (by 5.4%) compared to the control solid wood. Generally, It was found that the steamed wood samples resulted in higher mean MOR values in relation to that of the unsteamed wood samples. This is attributed to the better bonding performance of the steamed wood in comparison with to the unsteamed beech wood. Finally, it is concluded that the 10 mm finger length and the D3 durability class of the PVAc glue which resulted in the higher bending strength values is better to be used when finger jointed furniture lumber is produced either steamed or unsteamed beech wood.

Key words: finger joint, finger length, bending strength, beech wood, steamed, unsteamed

1. INTRODUCTION

Finger jointing has been in use in wood industry for many years, yet it is only with the decline in resource quality that interest in it for furniture has increased. Nonstructural finger joints are used if strength is not a primary concern. The benefits of finger joints in furniture and cabinet manufacturing are: 1) clear lumber from low grade stock, 2) less short length of waste material, and 3) increased yield of usable long parts (Jokerst 1981, Nestic and Milner 1993). Beech wood is one of the most important species for the furniture production in Europe. It is used mainly as steamed as well as unsteamed wood as raw material in many furniture applications. The potential use of beech wood the last years has gained increased importance in Europe. The reasons are increasing amounts of small and large diameter stems, which due to the knots and the red stain formation, can not be marketed for the furniture and veneer industry (Aicher et al 2001).

Polyvinyl acetate (PVAc) is one of the most common adhesives used in nonstructural applications. Polyvinyl resin emulsions are thermoplastic, softening if temperature is raised to a particular level and hardening again when cooled. They are prepared by emulsion polymerization of vinyl acetate and other monomers in water under controlled conditions. In emulsified form, the PVAc is dispersed in water and has a consistency and nonvolatile content generally comparable to thermosetting resin adhesives. PVAc is capable of producing strong and durable bonds on hardwood and hardwood - derived products. Although PVAc adhesives are not generally recommended for joints under continuous load or subjected to high temperatures and/or high humidity, these adhesives can be formulated for improved performance under such conditions. Thermosetting polyvinyl emulsions are modified PVAc emulsions and are more resistant to heat and moisture than are ordinary PVAc glues, and perform well in most nonstructural interior and protected exterior uses (Jokerst 1981, Sellers et al 1988, River 1994). Ordinary PVAc glues are marketed as milky, white fluids for use at room temperatures, classified in durability classes (D1, D2, D3 and D4), according to EN-204:2001 Standard.

Limited information is available on end gluing hardwoods, in contrast to softwoods, which have been extensively investigated and industrially utilized (Pena 1999). Pena (1999) studied the suitability of producing nonstructural finger joints made from beech wood (Fagus sylvatica) and European oak (Quercus petraea). He examined the effect of the geometry of finger joint in bending strength, using 9 mm and 12 mm finger lengths glued with melamine-uria-formaldehyle (MUF) and epoxy resin glues, and concluded that MOE of the jointed specimens did not differ significantly from the unjointed ones. On the contrary, the jointed specimens presented lower values of MOR than the unjointed ones (43%). Aicher et al (2001) studied the tension strength of finger joints in beech wood with 20 mm finger length and glued with melamine glue. They found that the mean tension strength of the finger jointed specimens was 70 ± 11 N/mm^2.

On the other hand, steam treatment is often applied to beech to improve the stability and permeability of the wood, obtain a desirable colour and soften the wood. The effect of steaming on the physical, mechanical and chemical properties of wood has been studied extensively. Generally, the process of steaming of the beech wood is accompanied by decrease of the strength (compression strength and MOE) and physical properties (density) of the wood (Yilgor 2001).

The objective of the study presented here was to examine the effects of finger length (4mm and 10mm) with respect to the PVAc gluing (D1, D2 and D3 durability classes), and finger orientation on bending strength of finger jointed steamed and unsteamed beech wood (Fagus sylvatica).

MATERIALS AND METHODS

Experiments were carried out with steamed and unsteamed beech wood with dimensions 50 x 30 x 400 mm. Natural defects were removed by trimming according to EN 385:2001. The material was placed in a conditioning room at 20° C and 65% relative humidity and allowed to reach a nominal equilibrium moisture content (EMC) of 12%. Two finger joints were performed by profiling cutterheads with the characteristics shown in Table 1 and Figure 1.

Table 1. Fingers configuration used in research

Fingers configuration	Values	
Length (l) (mm)	4	10
Pitch (p) (mm)	1.6	3.8
Tip (t) (mm)	0.4	0.16
Angle (α°)	12,0	11.0

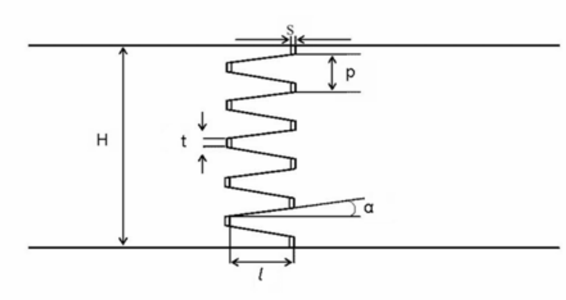

Figure 1. Geometry of finger joints

Following finger jointing, the blocks were glued in keeping with the technical recommendations provided by the adhesive manufacturers. Three classes of Polyvinyl-acetate (PVAc) based glues (D1, D2, and D3 durability classes) for interior use, were studied.

A one-face glue application by brush was used. The assembled joints were pressed manually with a constant end pressure for 60 sec. The jointed pieces were then cut to final dimensions 20 x 20 x 360 mm to produce bending strength samples. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) tests were performed in accordance with ISO 10983:1999 and DIN 52186:1978 standards with a Shimatzu machine. For each finger length the influence of the finger orientation (horizontal and vertical) with regard to the direction of the load was also examined (Figure 2). For every parameter 15 specimens were tested according to EN 385:2001. After each bending test two samples were cut from each side of the failed joint and moisture content (MC) and density were determined.

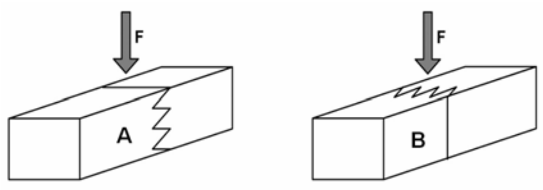

Figure 2. Orientation of finger joints and loading direction in samples ((A: horizontal and B: vertical fingers).

RESULTS AND DISCUSSION

Mean values of the bending strength properties measured on the unsteamed and steamed beech wood are given totally in Table 2. The average density of the unsteamed specimens was 0.605 g/cm^3 (std 0.052) and the average moisture content 10.1 % (std 0.171) whereas, the corresponding average of the steamed specimens was 0.595 g/cm^3 (std 0.022) and the average moisture content 10.4 % (std 0.235) .

We can see in this table, that the bending strength (MOR) of the tested unsteamed specimens fluctuated from 33.51 up to 82.24 N/mm^2 and affected by the finger length (4mm and 10mm), the durability class of glue (D1, D2, D3), and the orientation of the finger joints (horizontal and vertical). The higher percentage values compared to the solid wood values, appeared in the specimens with 10mm lengths with D3 glue class (75.7% in horizontal and 72.3% in vertical fingers). The corresponding bending strength (MOR) of the steamed tested specimens fluctuated from 34.9 up to 80.27 N/mm^2 and affected by the same factors as the unsteamed specimens (Finger length, PVAc glue class, Finger joints orientation). The higher percentage values compared to the solid wood values appeared also in the specimens with 10 mm lengths with D3 glue class (75.1% in horizontal and 73.6% in vertical fingers).

As we can see in Figure 3, in most cases the steamed wood specimens showed higher mean Modulus of Rupture values compared to the unsteamed wood specimens. This is attributed to the better bonding performance of the steamed beech wood in comparison with to the unsteamed beech wood. We know that steaming of wood causes mobilization and partial removal of extractives, which in turn affects wood specific gravity and makes bonding performance easier (Jilgor 2001).

Table 2. Bending strength properties of the finger jointed unsteamed and steamed beech wood

Finger joint orientation	Bending strength (N/mm^2)						
	Solid wood	Finger length (mm)					
		4			10		
		PVAc category			PVAc category		
		D1	D2	D3	D1	D2	D3
Unsteamed wood							
Horizontal fingers							
M.O.R.	108.71* (5.77)	33.51 (3.20)	56.02 (6.27)	61.49 (6.53)	52.51 (6.00)	65.20 (5.48)	82.24 (9.48)
M.O.E.	11643.0 (1130)	11169.0 (1892.6)	11054.0 (2268.1)	11692.0 (1201.7)	10839.0 (1334.7)	10408.0 (1200.7)	11828,0 (1064.0)
Vertical fingers							
M.O.R.	108.71 (5.77)	34.36 (4.31)	53.12 (5.11)	59.99 (5.16)	46.20 (6.61)	64.45 (3.80)	78.65 (6.08)
M.O.E.	11643.0 (1130)	11782.0 (1768.1)	11401.0 (1816.0)	11692.0 (1263.8)	11411.0 (1556.3)	10715.0 (1091.1)	12310.0 (986.2)
Steamed wood							
Horizontal fingers							
M.O.R.	106.81* (7.38)	36.53 (3.86)	66.89 (6.39)	71.52 (5.08)	46.11 (3.38)	73.96 (5.66)	80.27 (5.92)
M.O.E.	11163.8 (1246.6)	11734.0 (848.3)	11855.0 (994.3)	11468.0 (714.7)	12864.0 (1392.6)	12306.0 (1369.2)	11382.0 (1063.7)
Vertical fingers							
M.O.R.	106.81 (7.38)	34.90 (4.44)	60.49 (4.58)	68.98 (5.00)	41.78 (4.20)	72.89 (6.37)	78.65 (5.38)
M.O.E.	11163.8 (1246.6)	10963.0 (1161.9)	12197.0 (1085.8)	11140.0 (1085.0)	11872.0 (1127.1)	11978.0 (1189.8)	11517.0 (966.4)

* Mean values of 15 samples and standard deviation in parenthesis.

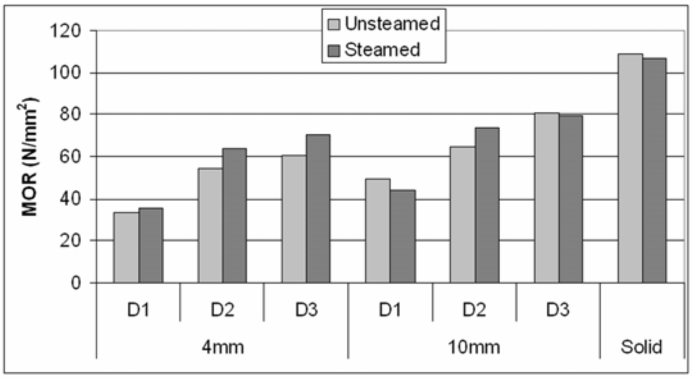

Figure 3. Effect of handling of material (steamed - unsteamed) on MOR of finger jointed beech wood (where: D1, D2, D3 are durability classes of PVAc glue)

As we can see in Table 2, the Modulus of Elasticity of the tested unsteamed specimens ranged from 10,400.0 N/mm^2 (in specimens with 10mm finger length glued with D2 glue class) up to 12,310.0 N/mm^2 (in specimens with 10mm finger length glued with D3 glue class). From these results it is concluded that finger jointing of the unsteamed beech wood didn't affect the MOE of the tested specimens in a distinct manner, which ranged in the same levels of the control solid wood (11,643.0 N/mm^2). The same conclusion is confirmed by the results given by Penna (1999) for unsteamed finger jointed beech wood.

On the other hand, the Modulus of Elasticity (MOE) of the tested steamed specimens in most cases appeared to be slightly higher (about 5.4% in mean values) than the corresponding MOE of the control solid wood (11,163.3 N/mm^2), and ranged from 10,963.0 N/mm^2 (in specimens with 4mm finger length glued with D1 glue class) up to 12,864.0 N/mm^2 (in specimens with 10mm finger length glued with D1 glue class). From these results it is concluded that finger jointing of the steamed beech wood resulted in slightly higher MOE of the tested specimens.

Effect of Finger length

The results in Table 2 show that Modulus of Rupture affected by the finger length (Figure 4). In all cases, specimens with 10mm finger length showed higher values of MOR than the specimens with 4mm finger length. The increase ranged in unsteamed wood from 16.4% in specimens glued with D2 glue class up to 56.7% in specimens glued with D1 glue class.

The corresponding increase, in steamed wood ranged from 10.6% in specimens glued with D2 glue class up to 26.2% in specimens glued with D1 glue class.

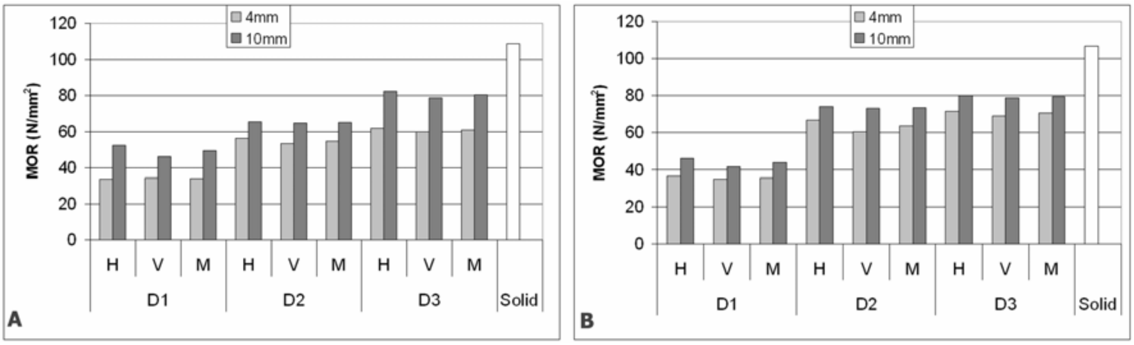

Figure 4. Effect of finger length on MOR of the unsteamed (A) and steamed (B) beech wood (Where: H is horizontal, V is vertical and M is without orientation of fingers)

Table 2 shows that Modulus of Rupture of both unsteamed and steamed beech wood affected by the PVAc glue class, in the same way.

In unsteamed wood, specimens glued with D3 glue class showed the higher values of MOR (from 59.9 up to 82.24 N/mm^2), specimens glued with D1 glue class the lower values (from 33.51 up to 52.51 N/mm^2), and specimens glued with D2 glue class intermediate values (from 53.12 up to 65.2 N/mm^2). In the case of specimens with 10mm finger length the increase in MOR by replacing the class of glue from D1 to D2 ranged from 19.5% up to 42.7%. Correspondingly, the increase in MOR by replacing the class of glue from D2 to D3 ranged from 7.6% up to 18.6%. In the case of specimens with 4mm finger length the increase in

MOR by replacing the class of glue from D1 to D2 ranged from 35.3% up to 45.4%. Correspondingly, the increase in MOR by replacing the class of glue from D2 to D3 ranged from 6.5% up to 12.3%.

In steamed wood, specimens glued with D3 glue class showed the higher values of MOR (from 68.98 up to 80.27 N/mm^2), specimens glued with D1 glue class the lower values (from 34.90 up to 46.11 N/mm^2), and specimens glued with D2 glue class intermediate values (from 60.49 up to 73.96 N/mm^2). In the case of specimens with 10mm finger length the increase in MOR by replacing the class of glue from D1 to D2 ranged from 60.4% up to 74.5%. Correspondingly, the increase in MOR by replacing the class of glue from D2 to D3 ranged from 7.9% up to 8.5%. In the case of specimens with 4mm finger length the increase in MOR by replacing the class of glue from D1 to D2 ranged from 73.3% up to 83.1%. Correspondingly, the increase in MOR by replacing the class of glue from D2 to D3 ranged from 6.9% up to 14.0%.

From these results we can conclude that the D1 class of the PVAc glue has the same very low effectiveness in the adhesion of both unsteamed and steamed beech wood specimens in regard to D2 and D3 glue classes.

From Table 2 and Figure 5, we can see that Modulus of Rupture affected by the orientation of the fingers. In unsteamed wood, it was found that, in most cases the horizontal fingers appeared higher MOR values (about 5%) than the vertical ones (with the exception of the specimens with 4mm finger length, glued with D1 glue class). In steamed wood, it was also found that, in all cases the horizontal fingers appeared higher MOR values (about 5.5% in mean values) than the vertical ones.

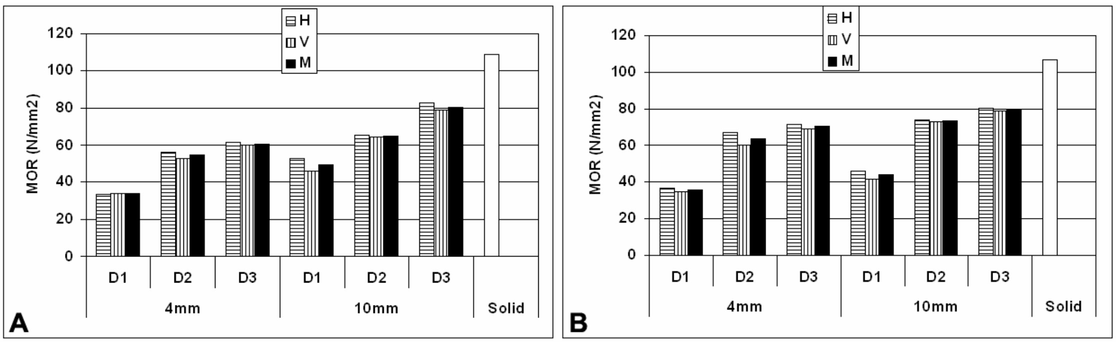

Figure 5. Effect of finger orientation on MOR of the unsteamed (A) and steamed (B) beech wood (Where: H is horizontal, V is vertical and M is without orientation of fingers)

CONCLUSIONS

Beech wood has a very good potential in finger jointed nonstructural uses. It is used mainly as steamed as well as unsteamed wood in many furniture applications. Within the range of parameters studied the bending strength (MOR) of the finger jointed beech wood was affected by the type of the PVAc glue (D1, D2, D3 durability classes), the finger length (4 and 10mm), the orientation of the finger joints (horizontal, vertical), and the handling of beech wood (steamed, unsteamed).

- Specimens with 10mm finger length showed higher values of MOR than the specimens with 4mm finger length.
- Specimens glued with D3 glue class showed the higher values of MOR, specimens glued with D1 glue class the lower values, and specimens glued with D2 glue class intermediate values.
- MOR affected by the orientation of the fingers. Specimens with horizontal fingers appeared higher MOR values than the specimens with vertical ones.
- In most cases, the steamed wood specimens showed higher MOR values than the unsteamed specimens.
- MOE affected by the handling (steamed, unsteamed) of the wood. MOE of the steamed specimens increased slightly (by 5.4%) compared to the control solid wood. MOE values for the unsteamed specimens was approximately the same with the control solid wood.

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