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STRENGTH OF FINGER - JOINTED BEECH WOOD (*FAGUS SYLVATICA*) CONSTRUCTED WITH SMALL FINGER LENGTHS AND BONDED WITH PU AND PVAC ADHESIVES

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Abstract:
As it is widely known, beech wood is one of the most important hardwood 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 research, the effects of the PVAc and PU adhesives and finger length (4.5mm, 6.5mm and 9.0mm), on bending strength of finger-jointed steamed and unsteamed beech wood (Fagus sylvatica), were studied. Modulus of rupture (MOR) and Modulus of elasticity (MOE) of unsteamed and steamed wood joints were measured. The MOR of unsteamed wood joints ranged from 22.26 to 47.41N/mm^2, whereas the MOR of the steamed wood joints ranged from 19.70 to 47.52N/mm^2. In both materials handling (steamed – unsteamed) the specimens with 9.0mm finger length showed higher MOR values. The MOE of the tested specimens fluctuated from 8960.9 up to 11852.9N/mm^2. The finger design and especially, the finger slope and the total surface of the fingers seemed to affect the MOR values.

Key words: *finger-joint; beech wood; steamed; unsteamed; PU; PVAc.*

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INTRODUCTION

The connection of finger joint has been in use in wood industry for many years, while the gradual decline of wood resources quality led to the increase of interest in this type of joint in furniture construction. Nonstructural finger joints are used if the mechanical strength is not a factor of primary concern. The use of finger joint in structural constructions, in furniture and in cabinet manufacturing has the benefits of producing clear lumber from low grade stock, less short length of waste material and increased yield of usable long parts (Jokerst 1981).

The main characteristics of a finger are pitch, length, slope, and width (Fig. 1). Research into the effect each variable has on joint strength is complicated, because there is an interaction between these variables. Finger length affects joint strength significantly, only when it is reduced to approximately the length of a single wood fiber. The main difference between a structural and a nonstructural finger-joint design is the width of the fingertip. In general, fingertips broader than 1.5mm should probably be classified as nonstructural or at least semistructural. At the other end of the scale, fingertips should not exceed 0.8mm to develop high strength structural joints (Strickler 1980). Yet, the smaller the fingertip is, the better the quality of the cutterheads structure material is necessary to be. Thus, the high cost of these cutterheads make some of the manufacturers to choose cheaper cutterheads, especially in nonstructural constructions, which have also fingertips of larger dimensions.

Polyvinyl acetate (PVAc), one of the most common adhesives used with solid wood, ordinarily is destined in market for use at room temperatures and is thermoplastic, softening in raised to a particular level temperatures and hardening when the adhesive cools. 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 to PVAc emulsions, being more resistant to heat and moisture, than the ordinary PVAc glues and perform quite well in most nonstructural interior and protected exterior uses (Jokerst 1981, Sellers *et al*. 1988). PVAc adhesives are classified according to EN-204:2001 standard in durability classes (D1, D2, D3 and D4), according to their durability and resistance to moisture, while it has also been proved that in dry conditions these categories refer also to strength of the adhesion (Vasileiou *et al.* 2006)

The polyurethane substances (polyesters of carbamidic acid) are widely known for their high chemical reactivity, their high cohesive strength, flexibility, good performance at low temperatures, at various speeds and degrees of polymerization. Mainly because these adhesives tend to wet effectively the surfaces and create easily hydrogen bonds to most substrates, they also develop excellent links to many materials and therefore, they are widely used in many applications (textiles, footwear, automobiles, wood products, glass, ceramics etc.). One of the main disadvantages of these substances is their high cost.

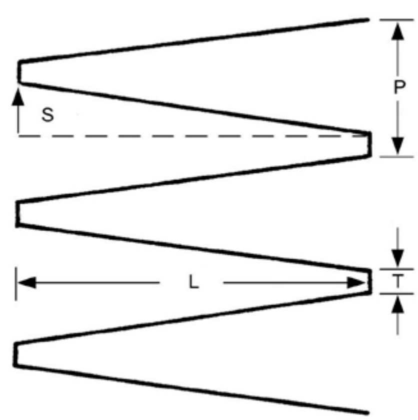

Fig. 1
Design variables of a finger-joint: Pitch (P), Length (L), Slope (S), and Width of fingertip (T).

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pp. 359-364

The polyurethane of one single substitute began to be applied in the adhesion of wood, quite recently. They are based on urethane prepolymers, obtained by reacting an excess of diisocyanate diphenyl methylene (MDI) with a polyol, in a way that a small amount of isocyanate monomer remains. Then, the free isocyanate groups of the adhesive react with the moisture of the substrate surfaces, in order to complete the bonding. The reaction of isocyanate with water proceeds through intermediate steps in the creation of urea linkages with the evolution of carbon dioxide. The carbon dioxide tends to cause the foaming and swelling of the adhesive and if this phenomenon is not properly controlled, several entrapped gas bubbles will weaken the cohesive strength of the bonding. Products of this type of adhesive are sold as liquids of one component, ready to use. Basically, they contain 100% solids that react and become hardened in contact with the air or wood moisture (Vick and Okkonen 1998).

Most of the researches, referring to the effect of the finger geometry in hardwoods, study mainly fingers of higher length and adhesives used in structural constructions (Avarkwa *et al.* 2000, Castro and Paganini 1997). Aicher *et al*. (2001) studied the tension strength of finger joints in beech wood with 20mm finger length and glued with melamine glue. They found that the mean tension strength of the finger jointed specimens was 70±11N/mm^2. The effect of the geometry of finger joint in bending strength, using 9mm and 12mm finger lengths glued with melamine-urea-formaldehyde (MUF) and epoxy resin glues of producing nonstructural finger joints made from beech wood (Fagus sylvatica) studied by Pena (1999) He concluded that MOE of the jointed specimens did not differ significantly from the unjointed ones, but the jointed specimens presented lower values of MOR than the unjointed ones (43%).

Vassiliou *et al.* (2007) studied the effect of three durability classes of PVAc bonding, and of two finger lengths (4mm and 10mm) with small tip and slope, on bending strength of steamed and unsteamed beech wood. They found that the higher MOR values derived from D3 adhesive class and 10mm finger length, and the lower MOR values derived from D1 durability class of adhesive, and the 4mm finger length.

Additionally, the effect of three different finger lengths (7, 14 and 21mm) were studied by Ozcifci and Yapici (2008), using oriental beech wood and PVAc adhesive.

The objective of the study, presented here, was to examine the effects of finger with small length and large slope on bending strength of finger jointed steamed and unsteamed beech wood (Fagus sylvatica) bonded with PVAc adhesive of D3 durability class and polyurethane adhesive. Part of these results concerning PVAc bonding was presented in a previous conference in Brasov (Vassiliou *et al.* 2009).

MATERIALS AND METHODS

Experiments were carried out with steamed and unsteamed beech wood originated from Greece. The material was transferred in the Wood Products Laboratory (Thessaloniki, Greece) for the procedure of finger joints forming and determination of joints strength. Natural defects were removed by trimming according to EN 385:2001. The material was placed in a conditioning room at 20^{0}C and 65% relative humidity and allowed to reach a nominal equilibrium moisture content (EMC) of 12%. Three different finger joints (the most commonly used in small Greek wood factories), were performed by profiling cutterheads with the following characteristics shown in Table 1. These specific cutterheads are frequently used mainly due to their low cost, which means that material of lower quality is used, resulting in the fact that characteristics like tip, slope and pitch are not the appropriate ones for the as high as possible joint strength. Following finger jointing, the blocks were bonded, keeping with the technical recommendations provided by the adhesive manufacturers. The Polyvinyl-acetate (PVAc) of D3 durability class and Polyurethane (PU) adhesives were studied.

Table 1

Configuration of the fingers used in the study

Fingers configuration	Values		
Length (l) (mm)	4.5	6.5	9.0
Pitch (p) (mm)	4.95	6.95	6.95
Tip (t) (mm)	1.3	1.3	1.3
Slope (mm/1mm)	0.28	0.37	0.24

A one-face glue application 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 20x20x360mm 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 every parameter 30 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.

Mean values of the density and the moisture content of the material used in the study are given in Table 2.

Table 2.

Wood properties of the material used in the study

Properties	Unsteamed	Steamed
	Mean (St.D.)	Mean (St.D.)
Density (g/cm3)	0.605 (0.052)	0.595 (0.022)
Moisture content (%)	10.1 (0.171)	10.4 (0.235)

RESULTS AND DISCUSSION

Mean bending strength values of unsteamed and steamed finger jointed beech wood were measured and all these values are given in Table 3.

As it is obvious from this table, the bending strength (MOR) of the tested finger jointed specimens fluctuated from 19.70 up to 47.52N/mm^2 and was affected by the finger length and the glue type but significant statistical differences between steamed and unsteamed wood were not observed. The higher percentage values compared to the corresponding values of solid wood, appeared in the specimens that have length of 9.0mm, glued with PVAc of D3 class adhesive (44.49% in steamed and 43.61% in unsteamed wood). However, these percentages were significantly lower than the corresponding percentage values that were recorded in a previous research work, where the same wood species (beech wood) and adhesive type were used, while the finger geometry and characteristics were different. According to that research, using even smaller length of finger (4mm) resulted in 47.83% and 28.12% higher mean values, than the corresponding values of the present research of steamed and unsteamed specimens with the length of 9.0mm (Vassiliou *et al.* 2007). On the contrary, in another previous study, the mean values of finger jointed oriental beech wood with 14 mm finger length bonded with PVAc adhesive presented strength values that barely reached the 24.16% of the solid wood values (Ozcifci 2008). Except for finger length and the other characteristics of finger joint, such as the pitch, slope and tip, seem to influence the bending strength, mainly through the configuration of the entire glued surface.

As one can observe in Table 3, the mean values of bending strength of tested finger jointed specimens bonded with PVAc adhesive of D3 class ranged between 22.28 and 47.52N/mm^2, while the mean values of the specimens bonded with polyurethane fluctuated from 19.70 up to 36.35N/mm^2. The lower MOR values of specimens bonded with PVAc were not recorded by the specimens with 4.5mm finger length, as it was expected, according to previous scientific results, whereas by the specimens with finger length of 6.5mm. That fact was attributed to the greater finger slope (0.37) of 6.5mm finger length, compared to 0.28 of the 4.5mm finger length. Concerning the specimens with polyurethane adhesive, the finger slope did not appear to influence the affect of finger length in the strength of joint.

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pp. 359-364

Table 3.

Bending strength of the finger jointed beech wood

Material	Solid	PU			PVAc		
		Finger length (mm)			Finger length (mm)		
		4.5	6.5	9.0	4.5	6.5	9.0
Unsteamed wood							
Bending strength (N/mm2)	108.71	22.26	28.12	35.52	35.97	22.28	47.41
Standard Deviation	5.77	2.82	1.53	2.96	3.68	2.67	4.46
Steamed wood							
Bending strength (N/mm2)	106.81	19.70	24.49	36.35	33.20	25.87	47.52
Standard Deviation	7.38	1.77	2.21	2.59	3.17	2.39	2.56

The specimens glued with polyurethane adhesive generally resulted in statistically significant lower values, compared to the respective specimens glued with PVAc of D3 class. That could be possibly attributed to the quite low moisture content of the specimens (approximately 10%), mainly because the adhesion procedure with polyurethane as an adhesive is accomplished with the reaction of free isocyanate groups of the polyurethane adhesive with the moisture of the substrate surfaces (Vick and Okkonen 1998). As several researches have already proved, the one-component polyurethane adhesive in green glued joints improved the strength properties in comparison to dry jointed joints (Pommier and Elbez 2006).

Table 4

Modulus of Elasticity of the finger jointed beech wood

Material	Solid	PU			PVAc		
		Finger length (mm)			Finger length (mm)		
		4.5	6.5	9.0	4.5	6.5	9.0
Unsteamed wood							
MOE (N/mm2)	11643.0	1112.5	8960.9	10122.3	11674.5	10545.2	10318.2
Standard Deviation	1129.7	928.2	771.1	1492.5	1583.2	1200.8	893.0
Steamed wood							
MOE (N/mm2)	11163.8	10007.6	11181.3	11852.9	9696.9	10253.2	11349.3
Standard Deviation	1246.6	928.2	1035.4	1126.8	888.4	906.2	950.4

The corresponding mean values of the MOE measured are given in Table 4. According to these results, the MOE of the tested specimens ranged from 8,960.9N/mm^2 (in unsteamed specimens with 6.5mm finger length bonded with polyurethane adhesive) up to 11,852.9N/mm^2 (in steamed specimens with 9mm finger length bonded with polyurethane adhesive). Based on these results it could be concluded that finger jointing did not affect the MOE of the tested specimens in a distinct manner, which ranged in the same levels of the control solid wood. The same conclusion was confirmed by the results given by Penna (1999) for finger jointed beech wood.

CONCLUSIONS

Solid beech wood is widely used in Europe as steamed as well as unsteamed wood in many furniture applications. Beech wood has also a very good potential in finger jointed nonstructural uses. Within the range of parameters studied the bending strength (MOR) of the finger jointed beech wood was affected by the adhesive type and the finger design (length and slope).

Specimens with 9mm finger length showed higher values of MOR than the specimens with 4.5 and 6.5mm finger length.

MOR was affected by the slope of the fingers. Specimens with the greater fingers slope and bonded with PVAc presented the lowest MOR values of all the other specimens.

Specimens bonded with PVAc of D3 glue class showed higher values of MOR than specimens bonded with polyurethane glue.

The MOR percentage values compared to the solid wood values were lower than 45%.

MOE was not affected in a distinct manner by the handling (steamed, unsteamed) of the wood, the finger design or the adhesive type.

Generally, the low cost and low material quality of the cutterheads resulted in roughly-cut characteristics of the cutterheads and lower joint strength.

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