BENDING STRENGTH PROPERTIES OF SOME FINGER-JOINTED OAKWOODS

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ABSTRACT

The purpose of this work was to study the utilization of small dimension finger jointed oakwoods for the manufacture of laminated wood for furniture production. Partcularly, it was examined the bending strength (modulus of rupture and modulus of elasticilty) of finger jointed laboratory specimens of turkey oak (*Quercus cerris* L.), hungarian oak (*Quercus conferta* Kit.) and holm oak (*Quercus ilex* L.), that were connected across the grain. Three different finger lengths (4mm, 10mm and 15mm), two finger orientations (horizontal and vertical), and three polyvinyl - acetate based glues for interior use (D1, D2 and D2 type) were investigated. From the results it can be concluded that MOR values of the finger jointed hungarian oak specimens fluctuated from 52,9 up to 112.1 N/mm^2, which correspond in a percentage level of 40,8 up to 86,6 % of the mean values of the solid wood (129.5 N/mm^2). The higher MOR values of the finger jointed specimens from turkey and holm oak correspond in a percentage level of 77,3 and 75,8 % compared with the mean values of the solid woods. The most effective finger jointed connections appeared on the hungarian oak specimens. The increase of finger length from 4 mm to 10 mm and 15 mm caused an increase in mean MOR values. The higher MOR values appeared on the specimens glued with D3 type of glue, the lower on the specimens glued with D1 type and the specimens glued with D2 type showed intermediate values. MOR values affected partly by the finger orientation. Modulus of elasticity (MOE) of all the joints studied was not affected by finger jointing and ranged in the same level values of the control solid wood, in all three species.

Key words: finger joint, bending strength, hungarian oak, turkey oak, holm oak

INTRODUCTION

Finger jointing is ubiquitous in wood industry. It is used in many structural and non-structural products. Nonstructural finger joints are used if strength is not a primary concern. They are used to join pieces of various lengths end grain to end grain from which natural defects have been removed and to join short lengths of material into lengths long enough to be useful. Non-structural products include furniture, cladding, fencing internal and external joinery (Jokerst 1981). In structural uses finger jointing is finally the major method to end joint lumber for the production of glue-laminated wood (Nestic and Milner 1993, Walker et. al., 1992). The other methods to end joint timber (*butt* and *scarf joints*) did not find industrial acceptance (River 1994, Koch 1972).

Any adhesive suitable for bonding wood technically could be used for bonding finger joints. Polyvinyl adhesives (PVA) are very common in non-structural applications. Polyvinil 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 PVA are dispersed in water and have a consistency and nonvolatile content generally comparable to thermosetting resin adhesives. PVA are marketed as milky –white fluids for use at room temperature in the form supplied by manufacturers. Thermosetting polyvinyl emulsions are modified PVA emulsions and are more resistant to heat and moisture than are ordinary PVA, and perform well in most nonstructural interior and protected exterior uses (Jokerst 1981, Tsoumis 1991).

Limited information is available on end gluing hardwoods in contrast with softwoods, which have been extensively investigated and industrially utilized (Pena 1999). Oak is the most abundant tree species in Greece (746,400 ha) and cover 49 % of the broadleaved Greek forests (about 2.5 million ha). Oakwood is produced from coppice forests in small dimensions and utilized almost exclusively as fuelwood and for charcoal production (Stamou 2001). The amount of the marketable Greek oakwood is more than 24 million m^3, which corresponds to a percentage level of 17,48 % of the total marketable amount of the Greek forests.

Hungarian oak (*Quercus conferta Kit.)* is present in almost all oak forests of the country and mainly in the mount of Pindos. The marketable amount of the Greek hungarian oak is about 7.67 million m^3, which corresponds to a percentage level of 5.56 % of the total marketable amount of the greek forests. Correspondigly, the percentage levels of turkey (*Quercus cerris L.*) and holm oak (*Quercus cerris L.*) are 1.19 and 0.6 % (Ministry of Agriculture 1992).

Pena (1999) studied the suitability of producing non-structural finger joints made from European Oak (*Quercus petraea L.*). He examined the effect of the geometry of finger joint in bending strength, using two different finger lengths (9 and 12mm). He concluded that modulus of elasticity of the jointed specimens did not differ significantly from the unjointed onesw. On the contrary, the jointed specimens presented lower values of modulus of rupture than the solid wood (43 %).

Hwang and Hsiung (2001) examined the properties of finger jointed and laminated compressed wood. From they results it is showed that finger jointed oak specimens showed lower values of MOR (up 73.9 %) and higher values of MOE (up to 118.72 %) compared to the solid wood.

MATERIALS AND METHODS

Experiments were carried out with small dimensions oak wood lumber with dimensions 50 x 30 x 400 mm of the following species: turkey oak (*Quercus cerris L.*), hungarian oak (*Quercus conferta Kit.*), and holm oak (*Quercus ilex L.*). Natural defects (knots, etc) were removed according to EN 385:2001. The material was placed in a conditioning room at 20^o C and 65% relative humidity and allowed to reach a nominal equilibrium moisture content (EMC) of 12%. Three finger joints were performed by profiling cutterheads with the following characteristics: a) 4 mm length, 0.4 mm tip, 1.6 mm pitch and 12.0^o angle, b) 10 mm length, 0.16 mm tip, 3.8 mm pitch and 11.0^o angle, and c) 15 mm length, 0.11 mm tip, 3.8 mm pitch and 7.5^o angle.

Following finger jointing, the blocks were glued in keeping with the technical recommendations provided by the adhesive manufacturers. Three types of Polyvinyl - acetate

(PVA) based glues (D1, D2, and D3) for interior use, were used. 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 (Picture 1). Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were measured according to ISO 10983:1999 and DIN 52186:1978 standards with a Shimatzu testing 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 1). 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.

Picture 1. Specimens of the finger jointed oakwoods.

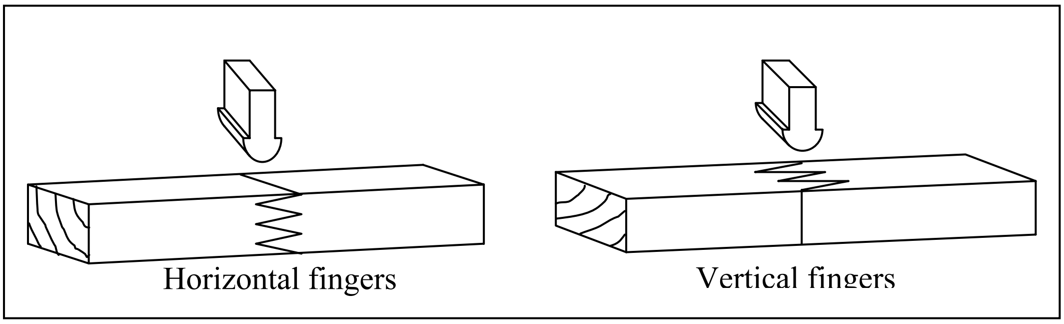

Figure 1. Finger orientation and loading direction in specimens.

The mean density of the hungarian oakwood specimens was 0.796 g/cm3 (std 0.0466) and the mean moisture content 10.1 % (std 0.62), the corresponding mean density of the turkey oakwood specimens was 0.778 g/cm3 (std 0.0353) and the mean moisture content 9.70 % (std 0.31), and the mean density of the holm oakwood specimens was 0.916 g/cm3 (std 0.0276) and the mean moisture content 9.76 % (std 0.28).

RESULTS AND DISCUSSION

The data of bending strength properties (modulus of rupture and modulus of elasticity) of all the materials tested are shown in Table 1.

Table 1. Bending strength properties of the materials tested.

Finger joint orientation	Bending Strength (N/mm^2)									
	Solid wood	Finger length (mm)								
		4			10			15		
		PVAc Category			PVAc Category			PVAc Category		
		D1	D2	D3	D1	D2	D3	D1	D2	D3
Hungarian oak *(Quercus conferta Kit.)*										
Horizontal Fingers										
MOR	129.5 (19.8)	57.6* (4.4)	73.9 (4.9)	89.4 (6.3)	66.3 (5.9)	91.9 (7.8)	103.8 (5.0)	78.5 (8.0)	103.1 (9.3)	108.6 (6.9)
MOE	13,492 (1,392)	14,336 (1,962)	14,644 (1,189)	13,895 (2,190)	12,854 (1,811)	14,281 (1,600)	15,572 (1,588)	9,456 (1,298)	11,725 (1,187)	13,665 (1,675)
Vertical Fingers										
MOR	129.5 (19.8)	52.9 (2.4)	70.5 (6.6)	87.4 (7.5)	66.2 (6.1)	88.4 (8.8)	103.3 (6.1)	81.1 (5.3)	109.9 (6.9)	112.1 (7.3)
MOE	13,492 (1,392)	11,398 (2,026)	13,751 (2,860)	13,536 (2,115)	11,416 (2,011)	13,691 (1,506)	14,300 (1,882)	10,437 (2,057)	13,363 (1,518)	13,894 (1,729)
Turkey oak *(Quercus cerris L.)*										
Horizontal Fingers										
MOR	134.0 (16.1)	44.1 (5.9)	68.4 (5.0)	83.7 (6.8)	61.1 (9.5)	83.6 (6.3)	97.9 (7.2)	76.5 (6.8)	97.8 (6.9)	103.6 (7.3)
MOE	12,268 (2,427)	8,230 (1,171)	9,829 (1,024)	9,963 (1,242)	9,534 (839)	10,513 (1,013)	10,963 (1,047)	11,464 (1,040)	10,559 (1,085)	10,741 (1,206)
Vertical Fingers										
MOR	134.0 (16.1)	49.5 (5.0)	67.7 (7.9)	82.5 (7.1)	68.6 (9.2)	85.6 (6.1)	98.2 (8.4)	76.2 (9.1)	97.2 (7.7)	103.4 (7.1)
MOE	12,268 (2,427)	10,521 (1,036)	10,626 (942)	10,243 (1,426)	10,239 (858)	10,749 (978)	10,876 (1,560)	10,709 (1,655)	11,078 (1,291)	10,964 (1,092)
Holm oak *(Quercus ilex L.)*										
Horizontal Fingers										
MOR	141.6 (15.8)	58.4 (6.5)	76.5 8.2)	90.5 (5.3)	67.6 (6.2)	83.7 (9.3)	97.4 (4.6)	81.4 (6.9)	92.9 (6.7)	104.7 (5.0)
MOE	12,141 (1,678)	11,819 (1,021)	11,337 (694)	11,932 (941)	10,632 (1,181)	11,205 (861)	12,795 (898)	10,559 (1,057)	10,519 (930)	11,476 (1,151)
Vertical Fingers										
MOR	141.6 (15.8)	55.9 (4.0)	85.2 (3.6)	90.1 (7.6)	76.7 (5.5)	90.5 (7.7)	99.4 (4.5)	86.1 (8.1)	98.5 (4.3)	107.4 (5.7)
MOE	12,141 (1,678)	12,324 (928)	11,418 (912)	12,596 (825)	11,302 (1,546)	11,752 (967)	11,724 (1,004)	10,419 (993)	10,975 (982)	11,196 (1,190)

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

Modulus of rupture

As it can be seen in Table 1, MOR values of the jointed specimens affected by the wood species, the type of glue, the finger length and the finger orientation.

MOR values of the hungarian oak specimens fluctuated from 52,9 up to 112.1 N/mm^2, which correspond in a percentage level of 40,8 up to 86,6 % of the mean values of the solid wood (129.5 N/mm^2). MOR values of the turkey oak specimens fluctuated from 44.1 up to 103.6 N/mm^2, which correspond in a percentage level of 32.9 up to 77.3 % of the solid wood (134.0 N/mm^2). MOR values of the holm oak specimens fluctuated from 55.9 up to 107.4 N/mm^2, which correspond in a percentage level of 39.5 up to 75.8 % of the solid wood (141.6 N/mm^2).

The most effective connections appeared on the hungarian oak specimens. For the specimens with 4 mm finger lengths, holm oak specimens are seemed to be more resistant than the turkey oak specimens. In this case MOR values of the finger jointed holm oak specimens correspond to a percentage level from 39.5 up to 63.6 % in regard to the solid holm wood, whilst the finger jointed turkey oak specimens correspond to a percentage level from 32.9 up to 62.5 % in regard to the solid turkey wood. The previous effect also exists for the glued with D1 type of glue specimens with 10 and 15 mm finger lengths. On the contrary, turkey oak specimens glued with D2 and D3 type of glue with 10 and 15 mm finger lengths are seemed to be more resistant than the holm oak specimens corresponding to the solid woods.

<u>Effect of the PVAc durability class on MOR</u>

The higher MOR values appeared on the specimens glued with D3 type of glue, the lower on the specimens glued with D1 type and the specimens glued with D2 type showed intermediate values. The change of the type of glue from D1 to D2 caused higher increase in MOR values than the corresponding change from D2 to D3.

For the hungarian oak specimens the increase in MOR values by changing the type of glue from D1 type to D2, fluctuated from 28.3 (for the specimens with 4 mm finger length in horizontal orientation) up to 38.61 % (for the specimens with 10 mm finger length in the same orientation). Correspondingly, the change of the glue type from D2 to D3 caused an increase in MOR values that flactuated from 2 (for the specimens with 15 mm finger length in vertical orientation) up to 23.97 % (for the specimens with 4 mm finger length in the same orientation).

For the turkey oak specimens the increase in MOR values by changing the type of glue from D1 type to D2, fluctuated from 24.78 (for the specimens with 10 mm finger length in vertical orientation) up to 36.82 % (for the specimens with 10 mm finger length in horizontal orientation). Correspondingly, the change of the glue type from D2 to D3 caused an increase in MOR values that flactuated from 5.93 (for the specimens with 15 mm finger length in horizontal orientation) up to 22.37 % (for the specimens with 4 mm finger length in the same orientation).

For the holm oak specimens the increase in MOR values by changing the type of glue from D1 type to D2, fluctuated from 14.13 (for the specimens with 15 mm finger length in horizontal orientation) up to 52.42 % (for the specimens with 4 mm finger length in vertical orientation). Correspondingly, the change of the glue type from D2 to D3 caused an increase in MOR values that flactuated from 5.75 (for the specimens with 4 mm finger length in vertical orientation) up to 18.30 % (for the specimens with the same finger length in horizontal orientation).

<u>Effect of finger length on MOR</u>

In all cases, the increase of finger length from 4 mm to 10 mm and 15 mm caused an increase in mean MOR values. This effect was more intense for the specimens glued with D1 and D2 type of glue.

For the hungarian oak specimens the increase in finger length from 4 to 10 and 15 mm caused an increase in MOR values, which flactuated from 4.62 up to 25.39 %. In most cases the increase of the finger length from 4 to 10 mm caused a higher increase in MOR values than the increase of the finger length from 10 to 15 mm. In the first case the increase fluctuated from 15.10 (for the specimens glued with D1 type of glue in horizontal orientation) up to 25.39 % (for the specimens glued with D2 type of glue in vertical orientation) and in the second from 4.62 (for the specimens glued with D3 type of glue in horizontal orientation) up to 25.39 % (for the specimens glued with D2 type of glue in vertical orientation).

For the turkey oak specimens the increase in finger length from 4 to 10 and 15 mm caused an increase in MOR values, which flactuated from 5.30 up to 38.59 %. In all cases the increase of the finger length from 4 to 10 mm caused a higher increase in MOR values than the increase of the finger length from 10 to 15 mm. In the first case the increase fluctuated from 16.97 (for the specimens glued with D3 type of glue in horizontal orientation) up to 38.5 % (for the specimens glued with D1 type of glue in both orientations) and in the second from 5.30 (for the specimens glued with D3 type of glue in vertical orientation) up to 25.2 % (for the specimens glued with D1 type of glue in horizontal orientation).

For the holm oak specimens the increase in finger length from 4 to 10 and 15 mm caused an increase in MOR values, which flactuated from 6.22 up to 37.21 %. The increase in MOR values by the increment of the finger length from 4 to 10 mm, fluctuated from 6.22 (for the specimens glued with D2 type of glue in vertical orientation) up to 37.21 % (for the specimens glued with D1 type of glue in the same orientation). Correspondingly, the increase in MOR values by the increment of the finger length from 10 to 15 mm, fluctuated from 7.49 (for the specimens glued with D3 type of glue in horizontal orientation) up to 20.41 % (for the specimens glued with D1 type of glue in the same orientation).

<u>Effect of finger orientation on MOR</u>

MOR values affected partly by the finger orientation.

Finger jointed specimens of the hungarian oak in horizontal orientation and with 4 and 10 mm fingers, showed higher MOR values than the specimens in vertical orientation. The opposite effect appeared for the specimens with 15 mm finger length.

In the case of the turkey oak finger jointed specimens, finger orientation did not affect significantly MOR values. Specimens in vertical orientation appeared higher MOR values (12.2 %) in the case of the glued with D1 type of glue and with 4 and 10 mm finger length.

Finger orientation did not affect holm oak specimens glued with D3 type of glue. Specimens in vertical orientation appeared higher MOR values (from 6 up to 11.37 %) in the case of the glued with D2 type of glue. The same effect appeared also in the glued with D1 type of glue specimens with finger lengths 10 and 15 mm.

Modulus of elasticity

As we can see in Table 1, MOE values of all the jointed specimens studied ranked from 8,230 up to 15,572 N/mm^2, not affected by finger jointing and ranged in the same level values of the control solid wood, in all three species.

MOE values of the hungarian oak specimens fluctuated from 9,456 up to 15,572 N/mm^2, which correspond in a percentage level of 70.1 up to 115.4 % of the solid wood (13,492 N/mm^2). MOR values of the turkey oak specimens fluctuated from 8,230 up to 11,464 N/mm^2, which correspond in a percentage level of 67.1 up to 93.4 % of the solid wood (12,268 N/mm^2). MOR values of the holm oak specimens fluctuated from 10,419 up to 12,795 N/mm^2, which correspond in a percentage level of 85.8 up to 105.4 % of the solid wood (12.141 N/mm^2).

<u>Effect of the PVAc durability class on MOE</u>

The hungarian oak specimens glued with D2 type of glue appeared higher MOE values than the specimens glued with D1 type. Also, the specimens glued with D2 and D3 type of glue appeared MOE values more or less the same compared with the solid wood.

The turkey oak specimens with 10 mm finger length appeared the higher MOE values on the glued with D3 type of glue specimens, the lower on the glued with D1, and with intermediate values on the specimens glued with D2 type.

The holm oak specimens glued with D3 type of glue appeared higher MOE values than the specimens glued with D2 type.

Effect of the finger length on MOE

The hungarian oak specimens with 15 mm finger length appeared higher MOE values than the specimens with 10 mm. For the turkey oak specimens the higher the finger length, the higher the MOE values. The opposite effect appeared for the holm oak specimens on which the higher the finger length of the specimens the lower their MOE values.

Effect of finger orientation on MOE

The hungarian oak specimens with 4 and 10 mm finger length appeared higher MOE values in horizontal orientation than the specimens in vertical. The adverse effect appeared on the specimens with 15 mm finger length.

The turkey oak specimens with 4 mm finger length in vertical orientation appeared in most cases higher MOE values than the specimens in horizontal.

The holm oak specimens with 4 mm finger length in horizontal orientation appeared higher MOE values than the specimens in vertical.

CONCLUSIONS

Based on this study, the following conclusions could be drawn for the examined oakwoods.

- MOR values of the finger jointed hungarian oak specimens fluctuated from 52,9 up to 112.1 N/mm^2, which correspond in a percentage level of 40,8 up to 86,6 % of the mean values of the solid wood (129.5 N/mm^2). The higher MOR values of the finger jointed specimens from turkey and holm oak correspond in a percentage level of 77,3 and 75,8 % compared with the mean values of the solid woods.
- The most effective finger jointed connections appeared on the hungarian oak specimens.
- The increase of finger length from 4 mm to 10 mm and 15 mm caused an increase in mean MOR values.
- The higher MOR values appeared on the specimens glued with D3 type of glue, the lower on the specimens glued with D1 type and the specimens glued with D2 type showed intermediate values.
- MOR values affected partly by the finger orientation.
- Modulus of elasticity (MOE) of all the joints studied was not affected by finger jointing and ranged in the same level values of the control solid wood, in all three species.

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