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COLOPHON

BONDABILITY OF CHESTNUT WOOD WITH PVAc ADHESIVES FOR FURNITURE PRODUCTION

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Abstract: The bondability of chestnut wood with PVAc adhesives of different durability classes, was investigated. Bending strength (MOR) of Chestnut wood finger joints ranged from 55.3 N/mm² (for 4mm finger length and the D1 class of the adhesive) to 83.5 N/mm² (for 20mm finger length and the D3 class of the adhesive), whereas for the control solid wood was 95.8 N/mm². The shear strength ranged from 7.89 N/mm² (bonded with D1 adhesive) to 9.20 N/mm² (bonded with D3 adhesive), which was equal to the shear strength of the solid chestnut wood. The application of the 3-hours water test caused a decrease of the tensile shear strength by 5.9% in mean values. The results also showed that there is a strong relationship between tensile shear strength and the bending strength (MOR) of the finger jointed chestnut wood.

Keywords: chestnut wood, bondability, finger joint, strength, PVAc adhesives

Introduction

1

European chestnut (*Castanea sativa* Mill.) is one of the more commonly occurring hardwood species of the Mediterranean Basin and of the central European area. Throughout Europe chestnut is present in at least 25 countries and covers a total area of 2.5 million ha. Chestnut wood, thanks to its good technological characteristics, the very much appreciated aesthetic properties, and its high natural durability is suitable for a great number of products, especially for furniture production and joinery applications (Fonti 2002, Militz et al 2003).

In wood materials, from the lowest to the highest quality, the selection and use of the right adhesive in the right way is of great importance and the right adhesive used properly is always the least expensive. The performance and behavior of adhesive systems for wood depend on a wide range of variables, such as the smoothness of the substrate surfaces, pH, presence of extractives, and amount of debris (Pizzi 1983).

On the other hand, polyvinyl acetate (PVAc) is one of the most common adhesives used in nonstructural applications. PVAc is capable of producing strong and durable bonds on hardwood and hardwood - derived products. (Sellers et al 1988). Ordinary, PVAc adhesives are odorless, nonflammable adhesives, and 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.

Shear strength is a frequently used reference for the evaluation of adhesive bond strength in solid wood because it is the most common interfacial stress under service conditions (Pizzo et al. 2003). Uysal (2006) evaluated the adhesive performance of the PVAc adhesives on bonding of beech wood, oak wood, scotch pine wood, and chestnut wood (*Castanea sativa* Mill.) that had been impregnated with creosote, tanalith-C and protim 230 WR-Parafin by the full cell methods and reported that impregnation process negatively affected the adhesive bonding shear strength.

Although, 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.

Limited information is available on end bonding 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*). Barboutis et al (2005) and Vassiliou et al (2006) studied the effect of finger length and the effect of PVAc bonding on the strength of finger-jointed steamed and unsteamed beech wood (*Fagus sylvatica*), correspondingly. The strength properties of some finger jointed oakwoods have been studied by Barboutis et al (2005) in holm oakwood (*Quercus ilex* L.), by Vassiliou et al (2005), and by Karastergiou et al (2006) in turkey oak (*Quercus cerris* L.).

The main objective of this study was to evaluate the bondability of small dimensions chestnut wood with PVAc adhesives. Particularly, the objectives were: a) to determine the shear strength of chestnut wood according to EN 205:2003 standard and b) to examine the effects of four finger lengths (4mm, 10mm, 15mm, and 20mm) with respect to the PVAc bonding (D1, D2 and D3 durability classes), and finger orientation on bending strength of finger jointed chestnut wood.

Materials and methods

Experiments were carried out with chestnut wood with 0.61g/cm² density. A special emphasis was put on the selection of the wood material to be without defects (knots etc.). The material was placed in a conditioning room at (20 ± 2) °C and (65 ± 3)% relative humidity and allowed to reach a nominal equilibrium moisture content (EMC) of 12%.



PVAc adhesives of three durability classes (according to EN 204:2001 standard) were applied under cold conditions (at room temperatures). The technological properties of the adhesives used (RAKOLL) are given in Table 1.

Table 1. Technological properties of the PVAc adhesives

Adhesive durability class	Trade name	Viscosity (M.Pa.s)	PH	Ash ratio (%)
D1	Express TO 50	14,000	7	50.18
D2	Express 45N	22,000	6	48.30
D3	LP 8022	13,500	3	50.77

Totally, 60 samples were prepared (10 samples for each parameter x 3 adhesive durability classes x 2 procedures - before and after being exposed to water resistant test). The prepared bonded test samples (Figure 1) were remained at $(20 \pm 2)^{\circ}\text{C}$ and $(65 \pm 3)\%$ relative humidity conditions for seven days. After that, half of the samples were immersed for 3 h in water at $(20 \pm 5)^{\circ}\text{C}$ followed by another seven days conditioning in standard atmosphere, according to EN 204:2001 standard. The tensile shear strength test of lap joints was carried out according to the procedure of EN 205:2003 standard. The way of loading the samples in tension is given in Figure 1.

3

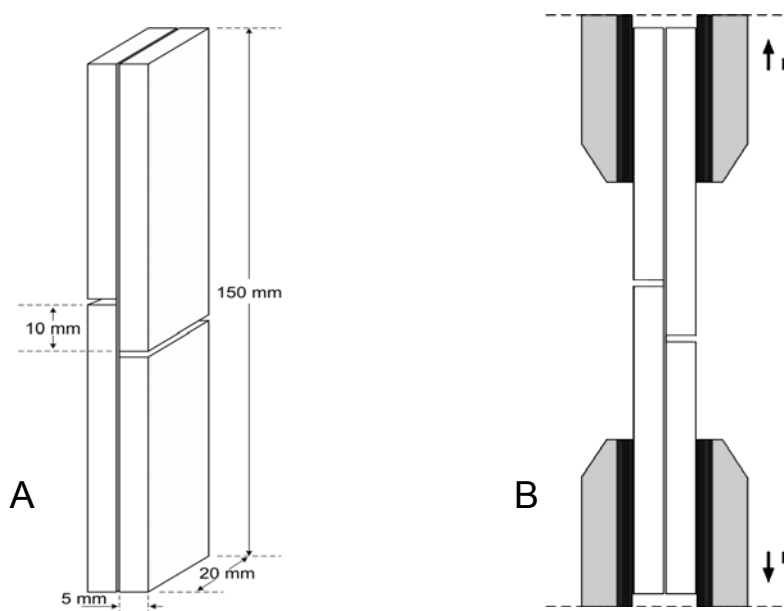


Figure 1. a) Configuration of the test sample and b) method of loading the samples in tension

Tensile shear strength of lap joints (σ_s) was calculated as follows:

$$\sigma_s = F_{\max} / A = F_{\max} / a \cdot b \text{ (N/mm}^2\text{)}$$



Where: σ_s is the tensile shear strength (N/mm²), F_{max} is the maximum load observed, A is the bonding surface of the sample in mm² (a is the width of bonded face, and b is the length of bonded face).

Furthermore, four finger joints were performed by profiling cutterheads with the following characteristics (Table 2).

Table 2. Fingers configuration used in research

Fingers configuration	Values			
Length (l) (mm)	4	10	15	20
Pitch (p) (mm)	1.6	3.8	3.8	6.2
Tip (t) (mm)	0.4	0.16	0.11	0.08
Angle (α°)	12.0	11.0	7.5	9.0

Following finger jointing, the blocks were bonded in keeping with the technical recommendations provided by the PVAc adhesive manufacturer (RAKOL). 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) tests were performed in accordance with ISO 10983:1999 and DIN 52186:1978 standards. 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.

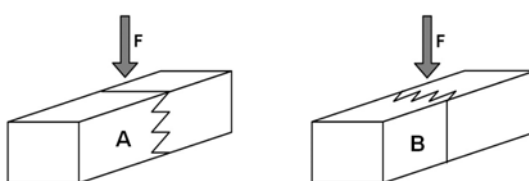


Figure 2. Orientation of finger joints and loading direction in samples ((A: horizontal and B: vertical fingers).

Results and discussion

Tensile shear strength

The results of lap-shear tests and interactions of adhesive durability classes and procedure are given in Table 3.



Table 3. Tensile shear strength according to the interaction of adhesive durability class and procedure

Adhesive Durability class	Procedure				Solid wood	
	7 days in standard atmosphere		7 days in standard atmosphere immersed for 3 h in water			
			7 days in standard atmosphere			
	Shear strength* (N/mm ²)	Standard Deviation	Shear strength (N/mm ²)	Standard Deviation	Shear strength (N/mm ²)	Sd
D1	7.89	1.89	7.33	0.72	9.20	0.71
D2	8.35	1.80	7.88	1.71		
D3	9.20	1.33	8.74	0.95		
Mean	8.48	--	7.98	--	--	--

* Mean values of 10 samples

Chestnut wood showed average shear strength of 8.48 N/mm² before water test and 7.98 N/mm² after water test. The highest shear strength values were found for D3 durability class of PVAc adhesive and the lowest values were found for D1 durability class. The obtained values of adhesive bonds before water test were found as strong as wood (9.20 N/mm²) in tension along the grain in D3 durability class and somewhat lower in D1 and D2 durability classes. Although, adhesives and adhesive bonds in praxis are not as strong as wood in tension along the grain, many adhesives are stronger than wood in shear parallel to the grain, at least up to wood density of about 0.7 - 0.8 g/cm³. Of course, in most cases, the measured strength of an adhesive bond is not the true strength of the adhesive but a strength peculiar to a combination of many factors, which include the strength and stiffness of the wood and the adhesive, bonding conditions, joint configuration, and environment (River et al 1991). Based on these results, it is obvious that PVAc adhesives are suitable for both non-structural and structural applications of interior uses.

Also, it was determined that when bonded samples were exposed to the 3-hours water test, their shear strength decreased by 5,9 % in mean values. The decrease was higher in D1 durability class of adhesive (by 7.1%) and lower in D3 durability class (by 5.0%).

In order to statistically evaluate the effect of adhesive durability class and procedure on shear strength a multiple variable analysis was performed. The difference between the groups regarding the effect of variance sources on shear strength has been not significant ($P \leq 0.05$), except of the D1 durability class after water test group which differed significantly from the D3 durability class group.

Finger jointed chestnut wood

Mean values of the bending strength values (MOR) measured on the chestnut wood are given totally in Table 4. The average density of the specimens was 0.57 g/cm³ (std 0.06) and the average moisture content 10.55 % (std 0.61).



Table 4. Bending strength (MOR) of the finger jointed chestnut wood

Adhesive Durability class	Modulus of Rupture (MOR) (N/mm ²)										
	Finger length (mm)								Solid		
	4mm		10mm		15mm		20mm		wood		
	N/mm ²	sd	N/mm ²	sd	N/mm ²	sd	N/mm ²	sd	N/mm ²	sd	
Vertical fingers										95.8	15.1
D1	55.3*	7.8	65.4	7.3	69.4	9.0	73.2	11.8			
D2	63.5	10.5	70.5	10.2	74.6	8.2	76.7	8.1			
D3	69.6	7.7	75.5	7.0	79.3	9.5	81.8	7.6			
Horizontal fingers											
D1	59.7	8.1	67.4	7.9	70.0	8.5	73.1	8.2			
D2	64.2	12.1	69.2	12.2	75.0	8.4	77.8	5.9			
D3	70.8	8.0	76.7	8.6	80.6	8.9	83.5	7.0			
Without orientation											
D1	57.5	7.95	66.4	7.6	69.7	8.75	73.2	10.0			
D2	63.9	11.3	69.9	11.2	74.8	8.3	77.3	7.0			
D3	70.2	7.85	76.1	7.8	80.0	9.2	82.7	7.3			

* Mean values of 15 samples.

We can see in this table, that the bending strength (MOR) of the tested specimens fluctuated from 55.3 up to 83.5 N/mm² and affected by the finger length (4mm, 10mm, 15mm, and 20mm), the durability class of adhesive (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 20mm lengths with D3 adhesive class (85.4% in vertical and 87.2% in horizontal fingers).

We see that Modulus of Rupture affected by the orientation of the fingers. It was found that, in most cases the horizontal fingers appeared higher MOR values (about 2%) than the vertical ones (with the exception of the specimens with 10mm finger length, bonded with D2 adhesive class, and of the specimens with 20mm finger length, bonded with D1 adhesive class).

The results in Table 4 show that Modulus of Rupture affected by the finger length. In all cases, specimens with 20mm finger length showed higher values of MOR than the specimens with smaller finger lengths. The increase ranged in samples with vertical fingers from 2.8% in comparison with specimens of 15mm finger length bonded with D2 adhesive class up to 32.4% in comparison with specimens of 4mm finger length bonded with D1 adhesive class.

The corresponding increase, in samples with horizontal fingers ranged from 3.7% in comparison with specimens of 15mm finger length bonded with D2



adhesive class up to 22.4% in comparison with specimens of 4mm finger length bonded with D1 adhesive class.

Table 4 and Figure 3 show, that Modulus of Rupture of all the finger lengths of chestnut wood affected by the PVAc adhesive class, in the same way. In samples with vertical orientation of fingers, specimens bonded with D3 adhesive class showed the higher values of MOR (from 69.6 up to 81.8 N/mm²), specimens bonded with D1 adhesive class the lower values (from 55.3 up to 73.2 N/mm²), and specimens bonded with D2 adhesive class intermediate values (from 63.5 up to 76.7 N/mm²). In the case of specimens with 20mm finger length the increase in MOR by replacing the class of adhesive from D1 to D2 was 4.78%. Correspondingly, the increase in MOR by replacing the class of adhesive from D2 to D3 was 6.65%. In the case of specimens with 15mm finger length the increase in MOR by replacing the class of adhesive from D1 to D2 was 7.49%. Correspondingly, the increase in MOR by replacing the class of adhesive from D2 to D3 was 6.3%. In the case of specimens with 10mm finger length the increase in MOR by replacing the class of adhesive from D1 to D2 was 7.8%. Correspondingly, the increase in MOR by replacing the class of adhesive from D2 to D3 was 7.1%. In the case of specimens with 4mm finger length the increase in MOR by replacing the class of adhesive from D1 to D2 was 14.8%. Correspondingly, the increase in MOR by replacing the class of adhesive from D2 to D3 was 9.61%.

In samples with horizontal orientation of fingers, specimens bonded with D3 adhesive class showed the higher values of MOR (from 70.8 up to 83.5 N/mm²), specimens bonded with D1 adhesive class the lower values (from 59.7 up to 73.1 N/mm²), and specimens bonded with D2 adhesive class intermediate values (from 64.2 up to 77.8 N/mm²).

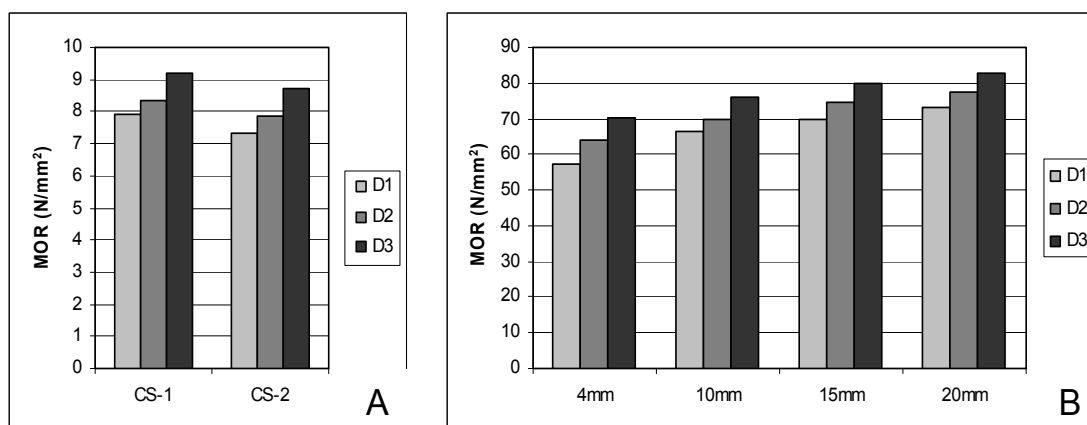


Figure 3. Effect of adhesive class on: A) Tensile shear strength (where CS-1 and CS-2 are conditioning sequences according to EN 205), and B) MOR of finger jointed, chestnut wood

As we can see in Figure 3 and the following Table 5 there is a strong relationship between tensile shear strength and the bending strength (MOR) of



the finger jointed chestnut wood. The results indicated that tensile shear strength corresponded to a percentage of the MOR values of the finger jointed samples, which ranged in mean values from 10.9% in 20mm finger length to 13.29% in 4mm finger length. This means that bending strength (MOR) of the finger jointed chestnut wood could be estimated with the help of the tensile shear strength measured values. The following formula can express the correlation between MOR value of the finger jointed chestnut wood and the tensile shear strength value:

$$\text{MOR} = \text{SS} \cdot (5 + 0.33D) + (30 - 60/\text{FL})$$

where SS is the Shear Strength, D=1,2 or 3 according to the adhesive durability class, and FL is 4,10,15,20 according to the finger length of the joints

Table 5. Analysis of tensile shear strength as percentages (%) of bending strength values of finger jointed chestnut wood

Adhesive durability class	Finger length			
	4mm	10mm	15mm	20mm
D1	13.7	11.9	11.32	10.78
D2	13.07	11.9	11.16	10.8
D3	13.11	12.09	11.5	11.12
Mean	13.29	11.96	11.33	10.9

Conclusions

Based on these results, it is concluded that tensile shear strength of chestnut wood bonded with PVAc adhesives of three durability classes is 8.48 N/mm² in mean values. This value does not differ significantly from the shear strength of the solid chestnut wood (9.20 N/mm²) particularly, the shear strength of D3 durability class of the PVAc adhesives. This permits the conclusion that PVAc adhesives are suitable for both non-structural and structural applications of interior uses.

The application of the 3-hours water test caused a decrease of the tensile shear strength by 5.3 %, in mean values.

Furthermore, chestnut wood has a very good potential in finger jointed nonstructural uses. It is used in many furniture and joinery applications. Within the range of parameters studied, the bending strength (MOR) of the finger jointed chestnut wood was affected by the type of the PVAc adhesive (D1, D2, D3 durability classes), the finger length (4mm, 10mm, 15mm, and 20mm), and the orientation of the finger joints (horizontal, vertical).

- Specimens with 20mm finger length showed higher values of MOR than the specimens with smaller finger lengths.



- Specimens bonded with D3 adhesive class showed the higher values of MOR, specimens bonded with D1 adhesive class the lower values, and specimens bonded with D2 adhesive class intermediate values.
- MOR affected by the orientation of the fingers. Specimens with horizontal fingers appeared slightly higher MOR values than the specimens with vertical ones (about 2%).

The results also indicated a strong relationship between tensile shear strength and the bending strength (MOR) of the finger jointed chestnut wood, which corresponds to a percentage given by the expression $MOR = SS \cdot (5 + 0.33D) + (30 - 60/FL)$.

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