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Bonding strength of polyvinyl acetate (PVAc) and casein adhesives in small diameter beech wood

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Abstract

As a matter of fact, beech wood is one of the most important commercial hardwood species in southeastern Europe. Beech is utilized mainly as round wood and fuel wood. Overall harvest of beech wood is comparable to those of pine and oak forests. Effective and maximum value use of small-diameter hardwood timber has long been of interest to forest managers and researchers. Gluing or bonding wood has been widely used for many centuries. Moreover, a wide variety of adhesives types is utilised, due to their extensive use in many different applications with wood. Beech wood (*Fagus sylvatica* L.), was used in order to investigate the bond ability of beech wood. For the bonding the used adhesives were PVAc and casein glue, both of D3. The adhesives were applied to one or two surfaces and the half of them were immersed in water in order to investigate the influence of moisture on bonding strength. According to the results, the average modulus of rapture was influenced by the type of adhesive. The samples of beech wood bonded with PVAc had higher modulus of rapture compared to the samples of beech laminated with glue Casein-gap from 1.03 to 2.2 N/mm². Additionally, the highest average modulus of rapture rate recorded in beech samples coated with PVAc on both bonding surfaces reaches 21.05 N/mm². The statistical analysis of the results revealed that the average bonding strength of those samples only air-conditioned, did not show any statistically significant difference from the average bonding strength of the samples immersed in water.

Key words: beech wood, bonding, casein, PVAc, shear strength

1. Introduction

Effective and maximum value use of small-diameter hardwood timber has long been of interest to forest managers and researchers. In addition to being a significant component of the standing forest base, small-diameter hardwoods often are available after thinning or other tending operations. Although the use of this material is important to achieving healthy and sustainable forests and other ecosystem management objectives, finding economical uses is sometimes difficult (Wiedendeck et. al., 2003)

Beech forests indigenously grow in central Europe, in the Balkan peninsula, from Greece and Bulgaria up to the Caucasus along the Black sea region and Turkey. As a matter of fact, beech wood is one of the most important commercial hardwood species in southeastern Europe (Ertekin et. al., 2015). Beech forests in Greece mainly grow at high altitudes on mountains; from mountain Oxia (Central Greece) up to the northern boarders. Furthermore, beech wood has an economic importance for Greece along with fir, pine and oak species. Beech is utilized mainly as round wood and fuel wood. Overall harvest of beech wood is comparable to those of pine and oak forests, that is, 300.000 m3 per year; 75 % of that comes from the public forests. In the Greek market, beech wood is utilized as sawn timber in furniture production, but a large amount is also used for fuel wood, boxes, top benches, pallets, toys and wood-based panels (particleboard, fibreboard). In the past, beech wood used to be treated with oil preservatives. In overall, beech wood is classified as a medium-high density hardwood (Skarvelis and Mantanis, 2010).

Gluing or bonding wood has been widely used for many centuries and it has been estimated that 70% of wood products are adhesive bonded in industrial practice (Gardner, 2006). Moreover, a wide variety of adhesives types is utilised, due to their extensive use in many different applications with wood (Frihart, 2005). Early glues used in furniture manufacturing were made from animals although, initially, they were supported and reinforced by wooden dowels and nails. Synthetic adhesives, qualified to hold parts of furniture even without any assistance, were discovered

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in the early 19th century due to the industrial development (Tout, 2000). However, a major disadvantage of the above adhesive was the considerable amount of time it took to harden in ambient conditions. Thus, a new category of adhesives, polyvinyl acetate (PVAc), was developed in 1950's replacing animal glues and a large proportion of the urea- formaldehyde used for almost 300 years. Adhesives used in construction and furniture assembly usually have long set times and are room-temperature cured. Furniture adhesives, in particular, are light-colored, of low-viscosity, and generally do not need much moisture resistance. On the other hand, construction adhesives, possibly being dark-colored generally have high viscosity and need flexibility (Frihart, 2005). Urea- formaldehyde, polyvinyl acetate (PVAc), casein glue, hot melts and polyurethanes are currently used as adhesives in furniture production (Tout, 2000).

Polyvinyl acetate (PVAc) is a thermoplastic adhesive, widely used in furniture, and has the crucial advantage of being harmless to human health and the environment. Casein glue, made from natural raw materials (milk), may contain calcium hydroxide and sodium which improve its properties though nowadays, its use is limited despite its strength and the fact that it shows no creep (Rowland, 1998). Burdurlu et. al. (2007) studied the effect of the wood surface, to be bonded, and the shear strength of beech and pine wood bonded with PVAc and urea formaldehyde. Consistent with the research results, higher shear strength was found in beech bonded with PVAc at bonding pressure 0.9 MPa. In general, PVAc offered better results in all samples, either radially or tangentially planed, compared to urea formaldehyde.

Konnerth et al. (2006) studied the behaviour and durability of beech wood bonded with casein, PVAc and other adhesives in accordance with EN 301-1:2004 standard. Researchers concluded that although PVAc provided better results than casein glue, the resistance did not show any statistically significant differentiation. Shear strength is a frequently used reference parameter for the evaluation of the adhesive bond strength in bonded wood products, as it is the most common interfacial stress under service conditions (Pizzo et. al., 2003).

2. Materials and methods

For the preparation of samples, beech wood (*Fagus sylvatica* L.), was used obtained from the market, conditioning in the laboratory for about 1 year under 20 ± 2º C and 65 ± 5 % relative humidity. Wood samples were weighed and then dried in the oven at 103 º C±2 for 24h and reweighed, according to ISO 3130:1975, in order to estimate the mean moisture content and the density of the material. The average density (oven dry weight/volume at current moisture content) and the average moisture content (Eq. 1) of the timber used was 0.63 (0.01) g/cm^3 and 8.8 (0.46) %. For the bonding the used adhesives were PVAc polyvinyl alcohol type D100 DUROSTICK manufactured six months before the test was carried out and casein glue powder AURO, both of D3 Class. In accordance with the specifications, the PVAc pH was 2.5 to 3.5, its density was 1.00 ± 0,10 Kg / L and its viscosity ranged between 8000 - 15000 mPa * s. The components of casein glue were: casein milk, lime, potash, chalk, borates, carbonates, silicates, and caseinates. The blending ratio of the glue powder and water is (1:1). On the sawn timber used, pairs of plates were prepared 1 cm thick, 12.5 cm wide and 34 cm long. Prior to bonding process, the plates had been planned and lightly smoothed with sandpaper No. 220. The glue spread out with the help of a special comb to the surface of one plate for every pair of plates for half the number of pieces, and for the other half it spread out on both plates. The amount of glue applied to each surface was 13 ± 1 g and it was calculated by weighing each plate separately before and immediately after applying it. Then, each pair of samples was placed in a press applying pressure (0.9 Mpa) for 3 hours. Before the formulation of the final samples (Figure 1, 2), the bonded plate was conditioned for a day until the adhesive's hardening was completed. The final specimens were conditioned for 7 days before the tests at 20ºC and 65% relative humidity. Half the number of the samples was immersed in water at 20 º C for three hours and then they were conditioned for seven days at 20± 2º C and relative humidity 65± 5 % according to EN 204:2001 standard. The tests were carried out according to standard EN 205:2003 on a universal testing machine (SHIMADZU UH-300kNA). The loading continued until a break or separation occurred on the surface of the test samples and the load speed was 5 mm/min. Fifteen replicated specimens were measured for the each test. Moreover solid wood samples were constructed as testifiers. Statistical analysis of the results was conducted by SPSS (PASW, 18) statistical program and specifically one way analysis of variance (ANOVA) was used to compare the differences of means at the 0.05 level, and determine any significant differences in the effect of the treatment combinations on the bonding strength.

3. Results

The measurement results of the tensile shear strength of bonded samples are presented in table 1. According to the results, regarding conditioned samples, the higher strengths were recorded in beech wood samples bonded with PVAc and with double-face glue application. Samples prepared with PVAchad higher bonding strength than 10 N/mm² as required by the EN 204:2001. The statistical analysis of the results indicated that the average bonding strength of solid wood samples did not show any unsignificant difference. According to the results (Table 1), the average bonding strength was influenced by the type of adhesive. In most cases, PVAc adhesive gave higher values compared to casein. Specifically concerning double glue application, the PVAc adhesive gave the highest strength in comparison with casein adhesive.

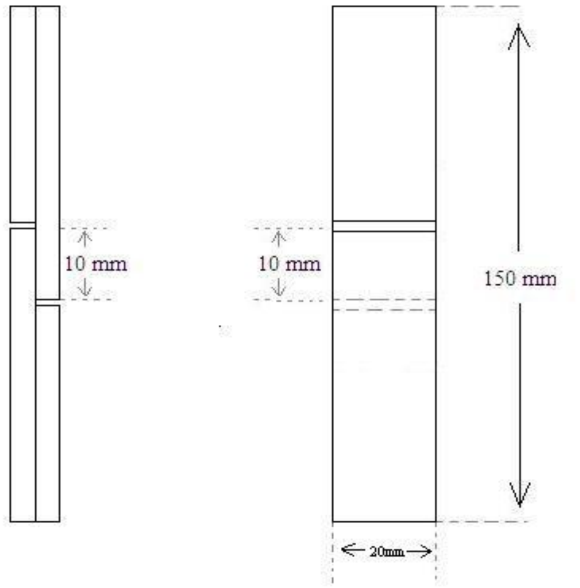

Figure 1. Configuration of the SampleEN 205:2003

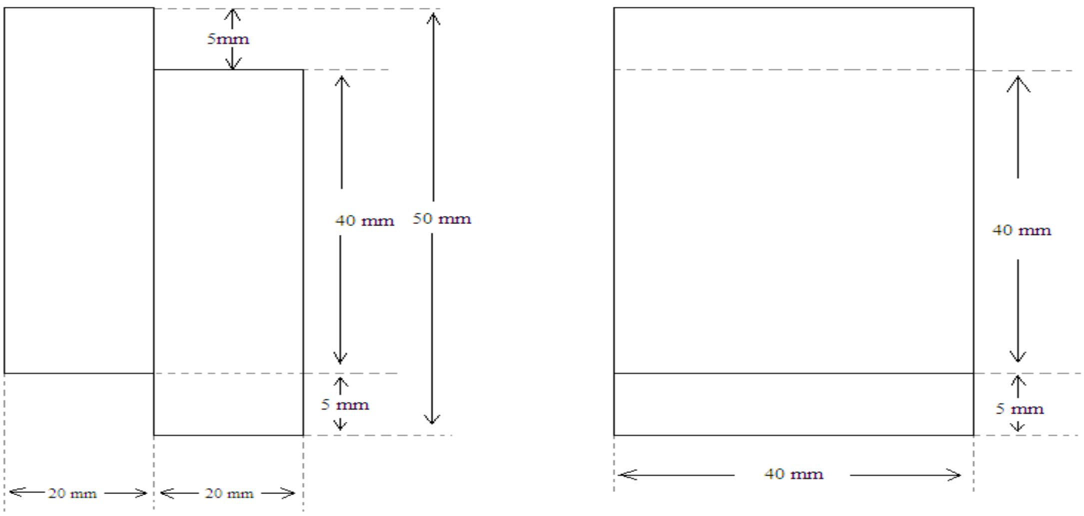

Figure 2. Configuration of the Sample ISO 6238:2001

Table 1. Mean values of tensile shear strength of beech wood

Wood species	**Bonding Strength N/mm²**								
	PVAc				**Casein**				**Solid wood**
	Conditioned		**Immersed**		**Conditioned**		**Immersed**		
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	
Beech	13.83* (2.25)	15.79 (0.63)	11.31 (1.11)	12.67 (1.78)	14.30 (3.12)	14.79 (1.05)	12.37 (2.41)	13.26 (3.04)	15.13 (1.40)

* Mean values of 15 samples with standard deviations are referred in parentheses. 1: Single surface glue application, 2: Double surface glue application, Conditioned: Specimens conditioned at 20ºC and 65% relative humidity, Immersed: Specimens immersed in water

On the other hand, it was found that the samples tested after the immersion, in most cases, retained their strength higher than 10 N/mm². According to the statistical analysis of the results given, the beech wood samples bonded with PVAc in single glue application differed statistically compared to solid wood. The statistical analysis of the results revealed that the average bonding strength of those samples only air-conditioned, did not show any statistically noticeable difference from the average bonding strength of the samples immersed in water. As seen from the results (Table 1) the average bonding strength was influenced by the choice of the adhesive coating either on one of the two or both bonding surfaces of the samples. It was observed that the samples coated on both surfaces with PVAc and casein have greater bonding strength compared to one side coated ones for most types of wood samples while statistical analysis shows that the average bonding strength of samples did not differ statistically significantly. Ozcifci et al. (2008) studied the influence of mechanical surface treatment of wood to be bonded with phenol formaldehyde, PVAc, urea formaldehyde and polyurethane, using beech, oak, pine and poplar woods. According to results, the higher strength samples were recorded in beech bonding with PVAc (14.83 N/mm²) in comparison with oak wood presented slightly lower values (13.68 N/mm²) and they concluded that beech bonded with PVAc is a great option for wooden constructions production.

Table 2. Mean values of shear strength of beech wood

Wood species	**Bonding Strength N/mm^2**				
	PVAc		**Casein**		**Solid wood**
	1	**2**	**1**	**2**	
Beech	19.98 (1.36)*	21.05 (3.19)	17,78 (1.65)	20.02 (1.72)	19.93 (0.81)

* Mean values of 15 samples with standard deviations are referred in parentheses. 1: Single surface glue application, 2: Double surface glue application

According to the results (Table 2) the average modulus of rapture was influenced by the type of adhesive. The samples of beech wood bonded with PVAc had higher modulus of rapture compared to the samples of beech laminated with glue Casein-gap from 1.03 to 2.2 N/mm². It was also found that the laminated beech samples recorded higher modulus of rapture than those of solid wood except from the single-face glue application samples bonded with casein, which showed a decrease of 2.15 N/mm². According to the statistical analysis of the results given the two types of adhesive did not present an important difference statistically. Finally, it should be noted that the highest average modulus of rapture rate recorded in beech samples coated with PVAc on both bonding surfaces reaches 21.05 N/mm². The statistical analysis of results shows that the average modulus of rapture of samples coated with adhesive on one surface do not significant differ statistically by the average modulus of rapture of samples coated in both bonding surfaces.

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