University of Belgrade
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ON THE OCCASION OF JUBILEE MARKING 90 YEARS OF ITS EDUCATIONAL, SCIENTIFIC AND PROFESSIONAL WORK, FACULTY OF FORESTRY ORGANISES THE INTERNATIONAL SCIENTIFIC CONGRESS

FIRST SERBIAN FORESTRY CONGRESS
under slogan:
- FUTURE WITH FORESTS -

Belgrade, Serbia, Belgrade University, Faculty of Forestry,
Kneza Viseslava 1, 11030 Belgrade
11-13 November, 2010.

The International Union of Forest Research Organizations (IUFRO)

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TOPIC D:
WOOD SCIENCE AND TECHNOLOGIES

Keynote papers:

Papers:

SHEAR STRENGTH BY COMPRESSION LOADING OF SOME HARDWOODS BONDED WITH PVAc AND CASEIN ADHESIVES

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Abstract: In this research, the shear strength of beech (*Fagus sylvatica*), common Lime (*Tilia europaea*), and oak (*Quercus robur*) woods, bonded with Polyvinyl Acetate (PVAc) and casein adhesives of D3 type, were studied, according to ISO 6238:2001. Two different ways of glue application were tested: a) a single-face glue application and b) double-face glue application.The results showed that Modulus of rupture (MOR) of all joints ranged from 14.90 N/mm ² to 21.05 N/mm ², and these values corresponded from 105.6% to 107.7% of that of the control solid wood. It was found that the mean MOR values of the bonded samples did not differ significantly from the mean MOR values of the corresponding solid wood samples, except for the oak wood samples bonded with casein adhesive, single face applied. Furthermore , it was found that beech wood resulted in higher average MOR compared to common Lime and oak wood samples, whereas, common lime samples resulted in the lower values in both the bonded samples and the corresponding solid wood samples. Also, it was found that the PVAc adhesive resulted in higher MOR values compared to the corresponding casein adhesive values. It was found that the double face glue application resulted in higher MOR values, in comparison with the corresponding samples bonded by single-face glue application in beech and common lime woods.

Key words: shear strength, PVAc, casein, beech, common lime, oak

INTRODUCTION

Wood bonding is a key factor of timber's efficient use. Adhesives are widely used in furniture industry for many years. The first glues used in furniture manufacturing were made from animals although initially were supported and reinforced by wooden dowels and nails. Synthetic adhesives that were qualified to hold parts of furniture without any assistance were discovered in the early 19th century due to the industrial development (Tout, 2000). One of the greatest discoveries of the time was the urea- formaldehyde adhesive which proved important for the development of furniture industry. A major disadvantage of the adhesive was the great hardening length at ambient conditions. Thus a new category of adhesives, polyvinyl acetate (PVAc), appeared in 1950's that replaced animal glues and a large proportion of the urea- formaldehyde that were used for almost 300 years. Urea- formaldehyde, polyvinyl acetate (PVAc), casein glue, hot melts and polyurethanes are currently used as adhesives in furniture production (Tout, 2000).

Acetic polyvinylesteras (PVAc) is a thermoplastic glue that is widely used in furniture and has the advantage of being harmless to human health and the environment.

Casein glue made from natural raw materials (milk) may contain calcium hydroxide and sodium that improves its properties (Rowland, 1998). Nowadays its use is limited despite its strength and the fact that shows no creep.

The wood species used in furniture production to the European market are mainly broadleaved and rarely coniferous. The main species are oak (Querqus sp.), beech (Fagus sp.), lime (Tilia sp.), ash (Fraxinus sp.), poplar (Populus sp.), maple, cherry, birch, walnut and pine. Beech and oak are the most important hardwoods in central and eastern Europe and used extensively in furniture (Pohler, 2005). Lime wood is considered excellent material for carving due to its low density and its uniform and fine texture and is used for furniture internal parts manufacturing (Cassens, 2007).

Konnerth et al. (2006) studied the behavior 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 differ significant statistically.

Keskin et al. (2009) investigated the adhesive ability of PVAc and other adhesives in wood of beech, oak and lime impregnated with non ingrained substances like vacsol azure. It was observed that beech wood is more resistant than lime tree wood.

Vassiliou et al. (2000) studied the bending strength of bonded finger joints beech wood with three categories (D1, D2, D3) of polyvinyl acetate adhesive. According to the results category D1 of polyvinyl acetate adhesive gave the least resistance, class D2 had greater resistance than category D1 and class D3 had the greatest resistance to bending.

Ozcifci et al. (2008) studied the influence of mechanical surface treatment of wood which is to be bonded and the effect of fiber direction in the process of gluing. The wood species used was beech, oak, pine and poplar. The adhesives studied were phenol formaldehyde PVAc, urea formaldehyde and polyurethane. According to the results, the higher strength samples were recorded in beech laminated with PVAc. Researchers

concluded that Beech bonded with PVAc is a great choice for wooden constructions' production.

Burdurlu et al. (2007) studied the effect of the surface of wood, which is to be bonded, the shear strength of beech and pine wood bonded with PVAc and urea formaldehyde. Consistent with the research results, higher shear strength was given by the 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 with urea formaldehyde.

The purpose of this research is to study the strength by compression loading of beech, oak and lime woods bonded with PVAc and casein adhesives.

METHODS AND MATERIALS

For samples construction the following wood species were used: beech (Fagus sylvatica), lime (Tilia cordata Mill.) and oak (Quercus robur). The average density of timber used were 630 kg/m3 (SD 51,15), 485 kg/m3 (SD 42,03), 680 kg/m3 (SD 48,38) while the average moisture was 8.8% (SD 0.46), 8.7% (SD 0.90), 9.7% (SD 1.54) respectively.

For the bonding the used adhesives were PVAc polyvinyl alcohol type D100 DUROSTICK manufactured in September of 2009 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 is water (1:1).

On the sawn timber that was used, pairs of plates were constructed thickness 2 cm, width 11.5 cm and length of 42 cm. The plates after having planed and lightly smoothed with sandpaper No. 220 were ready for bonding. The glue spread out with the help of a special comb to one of two panels for half the number of pieces and for the other half spread out on both panels. The amount of glue applied to each surface was 13 ± 1 g and calculated weighting 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, the bonded plate conditioned for a day until the adhesive's hardening was completed.

The final tests were carried out according to international standard ISO 6238:2001 and their final form is shown in Figure 1. For each combination 15 repetitions were acted out. Moreover seven solid wood samples were constructed as testifiers. The samples were conditioned before the experiment for six more days (total of seven) at 20 º C and relative humidity 65%.

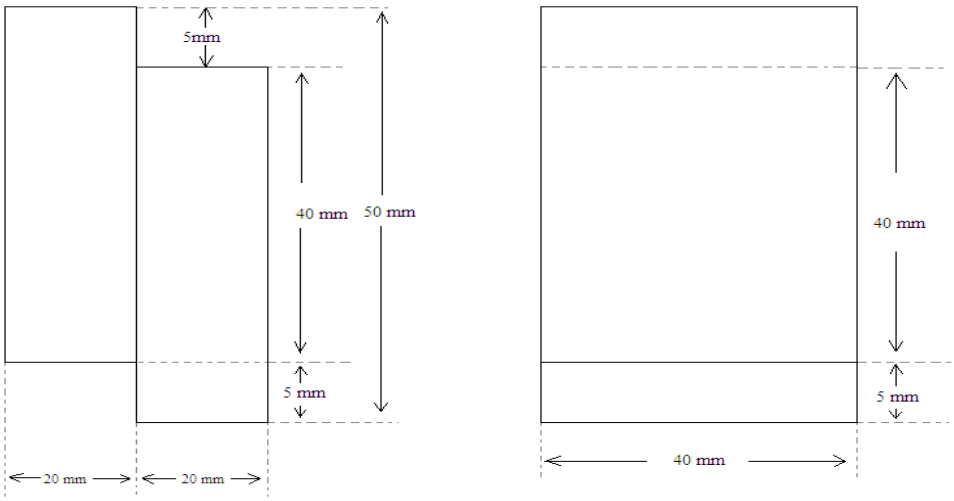

Figure 1. Configuration of the Sample

The samples were placed in a test machine and pressure applied with speed 8 mm / min until the sample broke. The modulus of rapture (T) calculated according to the formula:

$$T = \frac{F\,\max}{A} = \frac{F\,\max}{l * b}$$

Where Fmax: maximum force in Newton
A: bonded area in mm^2
l: length of bonded area in mm
b: width of bonded area in mm

Moreover, the detachment rate of wood recorded, lighting the damaged sample and the glue percentage that has remained on the surface of the wood.

RESULTS

The results of measurements of the shear strength by compressive loading of bonded samples of the three wood species are presented in total in table 1.

According to the results the average modulus of rapture of the three wood species used, ranged from 14.90 N/mm² (in samples of lime wood bonded with casein and with a single-face glue application) up to 21.05 N/mm² (in samples of beech wood laminated with PVAc and with double-face glue application). The statistical analysis of results showed that the average modulus of rapture of bonded samples did not significant differ statistically with the average modulus of rapture of solid wood samples. Furthermore, it was found that the highest average modulus of rapture was given by beech wood while the ash wood had the lowest prices both of bonded samples and of solid wood samples.

Table 1. Mean values of Shear strength

WOOD SPECIES	Modulus of Rapture N/mm^2				
	PVAc		CASEIN		Solid wood
	1 Single-face	2 Double-face	1 Single-face	2 Double-face	
BEECH	19.98* (1.36)	21.05 (3.19)	17,78 (1.65)	20.02 (1.72)	19.93 (0.81)
LIME	15.00 (1.10)	15,23 (1.45)	14,90 (3.33)	16.15 (1.05)	13,83 (0.64)
OAK	18.21 (1.64)	17,39 (2.05)	16,11 (2.54)	18.96 (1.73)	19,61 (0.76)

* Mean values of 15 samples with standard deviations in parentheses

According to the results (Table 1) 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.

The lime wood single-face glue application samples bonded with PVAc gave higher modulus of rapture compared to those bonded with casein glue. Lime samples coated in both surfaces recorded higher modulus of rapture than samples bonded with casein.

The bonded with PVAc samples of oak wood, presented greater modulus of rapture than the samples coated with an adhesive in a single surface.

In samples bonded with casein, however, samples coated with an adhesive on both bonding surfaces gave greater modulus of rapture.

Solid oak wood showed greater strength than the two types of bonded samples with a difference ranging from 0.65 N/mm² up to 3.5 N/mm² which was not observed in samples of beech and lime.

According to the statistical analysis of the results given the two types of adhesive did not present an important difference statistically in any of the three types of wood.

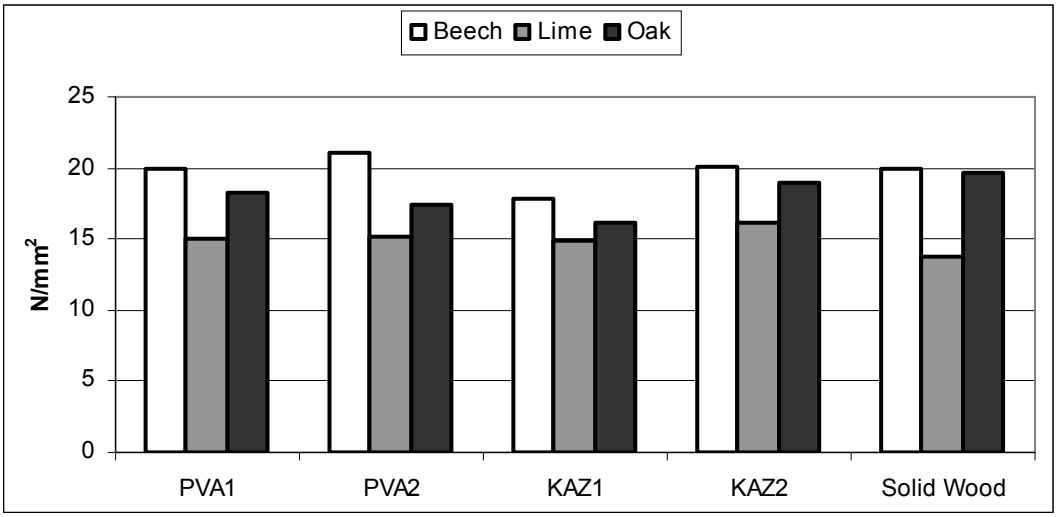

Figure 3. Effect of adhesive on Tensile strength by compression loading

As seen from the results (Table 1) the average modulus of rapture was influenced by the choice of the adhesive coated on one of the two or both bonding surfaces of the sample.

It was observed that samples coated on both surfaces with PVAc have greater modulus of rapture compared to one side coated only for beech and lime wood and vary by 0.07 N/mm² and 0.23 N/mm² respectively. In contrast, oak samples showed a reduction in modulus of rapture by 0.82 N/mm².

It was noticed that samples coated on both surfaces with casein glue provided increased modulus of rapture compared to samples coated on one side in all three wood types beech, ash and oak with a difference of 2.24 N/mm², 1.25 N/mm² and 2.85 N/mm², respectively.

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. While, the lowest rate observed in lime samples coated with casein glue to one surface reached 14.90 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 except the case of oak wood samples laminated with casein which means modulus of rapture of two types of spreads differed statistically significantly.

The averages and standard deviations of wood failure rates of wood for each class of bonded samples are shown in Table 2. The average values of wood failure rates ranging from 12.85% the lowest (in samples of beech wood glued with PVAc and coated with adhesive on both bonding surfaces) to 99.28% the higher (in lime samples bonded with PVAc and coated with adhesive bonding to a surface).

Table 2. Percentage of wood failure (%)

Wood species	Type of adhesive			
	PVAc		Casein	
	1 Single-face	2 Double-face	1 Single-face	2 Double-face
Beech	94.28% * (12.98)	85% (23.56)	54.64% (29.93)	12.85% (23.19)
Tilia	99.28% (2.58)	99.28% (2.58)	68.57% (35.55)	80.71% (28.65)
Oak	66.42% (13.87)	88.21% (15.45)	20% (18.12)	55.71% (22.61)

* Mean values of 15 samples with standard deviations in parentheses

Specifically, the results demonstrate that the samples of beech wood bonded with PVAc adhesive had very good bonding, where the average wood failure was 85% for samples coated with adhesive to both surfaces and 94.28% for samples coated only on one surface. These percentages illustrate that the bonding quality was very good. On the other hand, casein glue has not been proved so satisfactory since the wood failure rate was 12.85% for samples coated with adhesive to both bonding surfaces, although the average modulus of rapture of these bonded sample was very good indeed slightly greater than the wood failure in solid wood. For samples coated on one surface, the average wood failure was 54.64%.

In lime wood samples bonded with PVAc there was also a very good bonding quality and the wood failure was 99.28%.

The modulus of rapture of these samples ranged at lower rates than those of samples of beech and oak, although they displayed the highest rate of wood failure something that may be due to the relatively low density of the wood. The modulus of rapture of samples bonded with casein adhesive, even though they were smaller than those bonded with PVAc, were higher than those of beech and oak wood, and showed high value levels (68.57% and 80.71%), again assuming responsibility the density of wood.

Generally, the wood of oak generally had lower wood failure compared to beech and lime wood. The pieces of oak bonded with PVAc have higher wood failure (66.42% and 88.21%) compared to samples of oak bonded with casein adhesive (20% to 55.71%). Also, it is important to be noted that because the modulus of rapture of the bonded pieces of oak was lower than those of solid wood pieces, the bonding quality was not satisfactory.

Finally, comparing the percentages of damaged wood of a single-face glue application samples in a well of a both-face glue application samples, observed that the highest rates recorded, in dual spread samples apart from beech wood for both types of adhesive.

CONCLUSIONS

Based on these results, it is concluded that beech wood gave higher average MOR compared to common Lime and oak wood samples, whereas, common lime samples resulted in the lower values in both the bonded samples and the corresponding solid wood samples. Also, it was found that the PVAc adhesive resulted in higher MOR values compared to the corresponding casein adhesive values. It was found that the double face glue application resulted in higher MOR values, in comparison with the corresponding samples bonded by single-face glue application in beech and common lime woods.

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