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SHEAR BOND STRENGTH OF BLACK LOCUST WOOD GLUED WITH THREE ADHESIVE SYSTEMS

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ABSTRACT

Black locust wood was bonded with three commercial adhesives (PVAc, PU, epoxy) and tested for its shear bond strength against process (treatments I and II) and surface parameters (radial, tangential, roughness). For treatment I (applied pressure 8 bar, press time 1.5 h, curing time 24 h), the mean shear bond strength was found to be 6.95 $N.mm^{-2}$, 5.54 $N.mm^{-2}$ and 10.53 $N.mm^{-2}$ corresponding to the three adhesives tested, respectively. Increase in press and curing time in treatment II (press time 3 h, curing time 7 days) significantly improved the gluing performance of adhesives, 9.58 $N.mm^{-2}$ for PVAc, 13.32 $N.mm^{-2}$ for PU and 15.03 $N.mm^{-2}$ for epoxy. Surface of gluing (radial, tangential) did not affect the shear bond strength significantly. Failure within wood was found to be up to 40 % for treatment I (PVAc, epoxy) and up to 85 % for treatment II (epoxy). Positive linear regressions were calculated between shear bond strength and wood failure only for PU and epoxy adhesives. Shear bond strength was not related to surface roughness for any adhesive.

KEYWORDS: Shear bond strength, gluing, PVAc, polyurethane, epoxy, black locust.

INTRODUCTION

Edge- and end-gluing of black locust seems to be a necessary process in order the laminated wood to be used for interior and mainly exterior applications since timber is usually produced in small dimensions. Gluing of black locust wood with conventional exterior adhesives (resorcinol, PVAc, melamine) and mechanical machining of wood surfaces did not pose any particular problems. Less encouraging results were taken for polyurethane adhesives for which parameters, such as wood surface preparation and press applied during gluing, need to be investigated (Richter 2010a). It has been reported that primary processing, gluing, and sizing of black locust wood can be practiced reasonably well and the glued products are considered of high quality (Richter 2010b, Wittmann 1996). Some of the difficulties encountered limited to a) variable dimensions of wood pieces requiring more effort of handling and a higher number of steps, and b) frequency of growth defects reducing yield and increasing the number of operations required for producing high quality products.

It has been stated that higher extractive contents, especially on the surface layers of wood, may negatively affect the glue adhesion. However, removal of water soluble extractives from black locust wood surface by pressure steaming had no significant influence on polyurethane glue line strength (Richter 2010a).

So et al. (1983) found that the gluing strength of black locust specimens glued with urea resin adhesive was 24.2 $N.mm^{-2}$ and the wood failure was 99 %. Glue bond shear strength of black locust air-dried and planed wood surfaces glued with four adhesives varied from 9.0-15.4 $N.mm^{-2}$ (12.8 $N.mm^{-2}$ for PVAc, 9.0 $N.mm^{-2}$ for polyurethane, 13.0 $N.mm^{-2}$ for melamine and 15.4 $N.mm^{-2}$ for recorcinol) compared with the shear strength 17-19 $N.mm^{-2}$ of untreated solid wood (Richter 2010b). Jauernig (1997) found glue bond shear strength values as high as 10.5, 16 and 14.07 $N.mm^{-2}$ for the adhesives polyurethane, resorcinol-formaldehyde and melamine-formaldehyde, respectively.

The aim of this study was to further investigate the shear bond strength of black locust wood glued with three different adhesive systems: PVAc, polyurethane and epoxy.

MATERIAL AND METHODS

Wood specimens of black locust from Italy, Greece and Hungary (48 specimens per country) were properly cut from small bolts and machined (planed) to the final dimensions of 5x5x1 cm (length parallel to tree axis x width in radial or tangential direction x thickness in radial or tangential direction) according to ASTM D 905-89 (1989) standards. Surface roughness measurements on the radial and tangential wood surfaces of the produced specimens were carried out before gluing. Surface roughness was measured using a stylus profile measurement gauge (Mitutoyo Surface Roughness Tester SJ-301). From the above prepared wood specimens 72 wood-paired specimens were selected for gluing and testing (36 with radial surfaces and 36 with tangential surfaces).

Three commercial adhesive systems were used for gluing tests, a polyvinyl acetate (PVAc), a polyurethane (PU) and an epoxy adhesive (Tab. 1).

Tab. 1: Adhesive systems applied to black locust wood specimens.

Adhesive system	Provider
Polyvinyl acetate (PVAc)	ATLACOLL, M.Th. Pantazoglou S.A., Greece
Polyurethane (PU)	Power Adhesive (bisonite), BISON, The Netherlands
Epoxy	DURO Quick Set, Loctite Corporation, U.S.A.

For each type of adhesive and treatment, 12 wood-paired specimens were tested, 6 pairs with radial and 6 pairs with tangential surfaces. Gluing was carried out at room temperature (20-22°C). All gluing parameters (temperature, glue spread, etc.) were set according to manufacturers' recommendation. Glue application was done manually with a proper glue spreader to both glued surfaces and a constant pressure of 8 bar. Press time was 1.5 h and 3 h and curing time was 24 h and 7 days for treatment I and II respectively (Tab. 2).

Tab. 2: Gluing conditions and number of specimens tested.

Treatment / Adhesive	Pressure (bar)	Press time (h)	Curing time	No. of specimens*
Treatment I	8	1.5	24 h	
PVAc				12
PU				12
Epoxy				12
Subtotal				36
Treatment II	8	3.0	7 days	
PVAc				12
PU				12
Epoxy				12
Subtotal				36
Total				72

* For each treatment 18 specimens were collected with radial surfaces and 18 specimens with tangential surfaces

After 24 hours (treatment I) or 7 days (treatment II) from gluing, the adhesive bond in shear by compression loading was measured according to ASTM D 905-89 (1989) standard procedure by using an AMSLER testing machine.

RESULTS AND DISCUSSION

The shear bond strength ranged between 4.63 and 10.78 $N.mm^{-2}$ in treatment I and between 9.44 and 16.10 $N.mm^{-2}$ in treatment II for the three adhesive systems and for all wood-paired specimens either with radial or tangential surfaces (Tab. 3).

Tab. 3: Shear bond strength of black locust.

Adhesive		Shear bond strength[1] (N.mm^{-2})								t (between treatments I and II)		
		Treatment I				Treatment II						
		Rad.	Tang.	t	Rad.+Tang.	Rad.	Tang.	t	Rad.+Tang.	Rad.	Tang.	Rad.+Tang.
PVAc	x̄	7.30^a	6.60^a	1.312^{ns}	6.95^a	9.44	9.73^a	0.527^{ns}	9.58^a	6.131*	4.593*	6.893*
	s±	0.40	1.24		0.95	0.76	1.12		0.92			
	n	6	6		12	6	6		12			
PU	x̄	4.63^b	6.45^a	2.676*	5.54^a	12.44	14.20^b	0.921^{ns}	13.32b	4.642*	6.894*	7.501*
	s±	1.17	1.18		1.47	3.95	2.49		3.28			
	n	6	6		12	6	6		12			
Epoxy	x̄	10.28^c	10.78^b	0.435^{ns}	10.53^b	13.97	16.10^b	0.885^{ns}	15.03^b	1.775^{ns}	3.211*	3.441*
	s±	2.67	0.76		1.89	4.33	3.99		4.12			
	n	6	6		12	6	6		12			
	F	16.659*	30.937*		35.982*	2.739^{ns}	8.252*		9.785*			

[1] Values followed by a different letter within a column are statistically different for P < 0.05 (ANOVA and Tukey HSD Test)

* significant differences for P < 0.05

ns non significant differences for P < 0.05

In treatment II, the mean values for the three adhesives tested (PVAc, PU, Epoxy) were 9.58, 13.32 and 15.03 N.mm^{-2}, respectively. By comparing these values with previous results, Richter (2010b) found a little higher shear bond strength for PVAc (12.8 N.mm^{-2}) but lower values for PU (9.0 N.mm^{-2}). Lower values for PU (10.5 N.mm^{-2}) were also found by Jauernig (1997). Shear bond strength values found for other adhesives like melamine (13.0 N.mm^{-2}) and recorcinol (15.4 N.mm^{-2}) (Richter 2010b) as well as for melamine-formaldehyde (14.07 N.mm^{-2}) and resorcinol-formaldehyde (16.0 N.mm^{-2}) (Jauering 1997) are comparable to those found in this work for epoxy resin (15.03 N.mm^{-2}). The highest shear bond strength values (24.2 N.mm^{-2}) have been reported for the adhesive urea (So et al. 1983).

Statistical comparisons (ANOVA and t-test for P < 0.05) among the adhesives systems for different treatments and wood surfaces are shown in Tab. 3. For both treatments, significant differences existed in shear bond strength among the adhesive systems with the only exception of treatment II and specimens with radial surfaces. In treatment I, the epoxy adhesive was found to be superior to PVAc and PU for all cases (radial, tangential, radial + tangential). PVAc in general had higher values than PU in treatment I but differences were significant only for specimens with radial surfaces. With the exception of epoxy adhesive and specimens with radial surfaces, increase of press and curing time resulted in significantly higher shear bond strength for all adhesives. The improvement in shear bond strength performance in treatment II was more evident for the PU adhesive exceeding significantly the values of PVAc adhesive and approaching the values of epoxy adhesive. In conclusion, the epoxy adhesive proved to perform better for both treatments but limiting factors such as the high-cost and the lack of acceptance for applications that require durability (Frihart 2005a) should be also considered in gluing widely black locust wood. For both treatments, shear bond strength did not differ significantly between specimens with radial and tangential surfaces except for PU adhesive. It seems that the plane of cut (radial, tangential) does not exhibit major effects on the resulting bonding of black locust wood.

Failure of adhesive joints occurred partly in the bulk phase of wood and partly in the bulk phase of adhesive. According to Tab. 4, for all adhesives and wood surfaces the failure

Tab. 4: Failure of adhesive joints within wood of black locust.

Adhesive	Wood surface	Failure within wood (%)	
		Treatment I	Treatment II
PVAc	Radial	20-30	10-30
	Tangential	15-40	20-50
PU	Radial	0-5	0-30
	Tangential	0-5	5-15
Epoxy	Radial	5-40	10-70
	Tangential	5-30	5-85

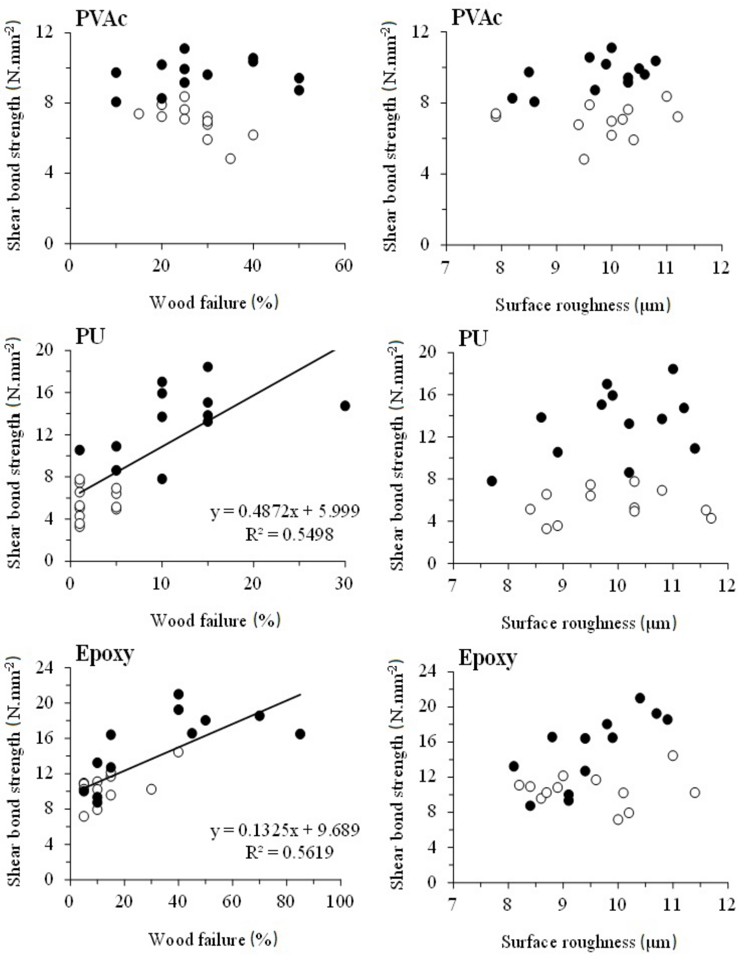

Fig. 1: Relationship between shear bond strength and wood failure (right) and between shear bond strength and surface roughness (left) of black locust wood specimens glued with different adhesive systems. Note: Treatment I (○), Treatment II (●)

proportion of adhesive joints in the bulk phase of wood was lower (5-40 %) than within adhesive (60-95 %) in treatment I. In the two stronger adhesives (epoxy, PVAc) of treatment I the failure proportion within wood was higher (5-40 %) than in PU (only 5 % in a few samples). The higher press and curing times of treatment II improved considerably the performance of epoxy and PU adhesives as judged by the increase in the failure proportions within wood (up to 30 % and 85 % for PU and epoxy, respectively) while PVAc showed no marked difference. Strong positive linear relationships were found between shear bond strength and wood failure proportion for epoxy and PU adhesives but not for PVAc (Fig. 1).

Tab. 5: Roughness values of radial and tangential surfaces of black locust wood specimens (mean values and minimum-maximum values in parenthesis).

Adhesive	Roughness (μm)						
	Treatment I			Treatment II			Total
	Rad.	Tang.	Rad.+Tang.	Rad.	Tang.	Rad.+Tang.	Rad.+Tang.
PVAc	9.76 (7.7-12.6)	9.77 (7.5-12.0)	9.76 (7.5-12.6)	9.73 (8.2-11.1)	9.75 (8.0-12.5)	9.74 (8.0-12.5)	9.75 (7.5-12.6)
PU	10.08 (7.8-13.2)	9.67 (7.7-11.0)	9.86 (7.7-13.2)	9.58 (7.2-11.8)	10.27 (7.4-12.5)	9.93 (7.2-12.5)	9.89 (7.2-13.2)
Epoxy	9.60 (8.0-12.0)	9.37 (7.1-12.2)	9.48 (7.1-12.2)	9.47 (7.7-10.6)	9.48 (7.0-12.6)	9.48 (7.0-12.6)	9.48 (7.0-12.6)

Besides the parameters related to adhesives (curing, thickness of glue phase, viscosity, type of glue, etc.), the characteristics of wood surfaces (roughness, good contact between surfaces, etc.) are also factors that may affect the bonding strength (Frihart 2005b). Effects of surface roughness on wood gluability have been well researched with the most obvious effect being a reduction in the size of the contact area, leading to a diminishment of the effective bond line (Collett 1972). Rough surfaces may lead to dryout, over-penetration, or starving of the adhesive while on the other hand may promote mechanical interlocking of the adhesive (Neese at el. 2004, Follrich et al. 2010). In our case, roughness values of radial and tangential surfaces were more or less similar among specimens used for each adhesive test (Tab. 5) and thus did not play a particular role in shear bond strength (Fig. 1).

CONCLUSIONS

The conclusions are summarised as follows:

- All commercial adhesive systems used in the experiment glued the wood surface of black locust. The bonding strength values for usual handling conditions (treatment I) cover the low values of wood shear strength for some wood species (lime, alder, spruce, fir, poplar, etc.). For higher wood strength values, epoxy adhesive seems to be the most suitable.
- The epoxy adhesive was found to be the best for both treatments and PVAc was slightly better than PU in treatment I. The higher press and curing times applied in treatment II significantly improved the performance of PU adhesive approaching the shear bond strength values of epoxy.

- The surface of gluing (radial, tangential) did not seem to affect the shear bond strength of PVAc and epoxy adhesives.
- Failure within wood was found to be small in treatment I, especially for PU adhesive. In treatment II, the failure proportion within wood increased considerably for epoxy adhesive but for PVAc and PU better joints are still needed for the requirements of the industry to cover all applications.
- Shear bond strength was related positively with wood failure in the case of PU and epoxy adhesives while it was not related with surface roughness.

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