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INFLUENCE OF MOISTURE CONTENT FOR BONDING QUALITY OF EUROPEAN BEECH AND ENGLISH OAK

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Abstract

This study focused on the comparison of the bonding quality of European beech (*Fagus sylvatica L.*) and English oak (*Quercus robur L.*), due to variability of moisture content (MC) in the wood. Hardwood species as a material, often yield a more difficult drying process, which can cause problems between various MC in the process of bonding. Specimens were bonded in two groups of MCs: 10/10% (control) and 6/14%. After reaching the equilibrium MC in standard conditions, specimens were cut into sample dimensions. Afterward the specimens were tested for bonding quality according to the EN 13354. In general, there is increase of the bonding quality for both hardwood species in different MC specimens. Statistically significant increase was notable in oak. With exception of the MUF adhesive, there were statistical difference between control and 6/14% MC group for oak.

Keywords: hardwood, polyurethane, polyvinyl acetate, urea formaldehyde, melamine urea formaldehyde, moisture content of wood

INTRODUCTION

The process of bonding of solid wood panels, is significantly affected by the moisture content (MC) in wood as well as water contained in an adhesive. MC directly influences the curing process and properties of an employed adhesive, economic costs (consumption of adhesive, pressing time) as well as physical and mechanical properties of final product (Vick, 1999; Bekhta *et al.,* 2014).

Bonding of observed species with a MC lower than 8% involves the following disadvantages: high consumption of energy for drying, brittleness of wood, rapid adhesive viscosity increases by diffusion of water into the cellular structure, worsened wetting and insufficient transfer of adhesive from one substrate to another (Bekhta *et al.,* 2014). In contrast, bonding of wood with MC higher than 8% has the following disadvantages: increasing adhesive penetration by the flow inside the vessel network, ultimately decreasing the viscosity of the applied adhesive layer (Bekhta *et al.,* 2014).

Aqueous adhesives tend to dry out when applied to wood below a MC of 6%. Wood absorbs water from the adhesive at a rate that adhesive flow and penetration into the substrate is drastically inhibited, even under high pressure. Below 3% MC, wood may become so dry that it temporarily resists wetting by the adhesive. This is due to the insufficient bound water to the wood to establish intermolecular attraction forces with water in the adhesive (Vick, 1999).

There are different types of adhesives used in solid wood panel manufacturing. Each type of adhesive forms a different cohesive interface with substrate. These various forms can include solidification, polycondensation, etc. Solidification of polyvinyl acetate (PVAc) is characterized by a physical process, initiated by the loss of the water contained in the adhesive dispersion. Under the consolidation pressure applied on the adherents, an adhesive film is formed, and repulsive forces between the PVAc molecules are resolved and the adhesive layer becomes solidified (Dunky and Niemz, 2002; Habenicht, 2006).

Another type of adhesive, polyurethanes (PUR) consist of polyol-isocyanate prepolymers with active isocyanate groups that react with the moisture present in wood, generating carbon dioxide (CO_2). This isocyanate groups also partly interacts with the hydroxyl groups (OH) of the adherent surfaces (Dunky and Niemz 2002; Habenicht 2006).

Urea formaldehyde (UF) is considered to be the most important amino resin bonding agent in engineered wood products. UF resin is commonly found in engineered wood products intended for internal use, without high moisture exposure. Hardening of UF is due to a hardener activated reaction, where UF resins continue to react by polycondensation to the hardened state and are accompanied by a partially loss of water (Dunky and Niemz, 2002; Habenicht, 2006).

Fortified MUF resin is based on the addition of melamine into the UF resin improves the resistance of UF bonds to water and weather (Dunky, 1998; Cremonini and Pizzi, 1999). Due to poor solubility of melamine in cold water, the resistance of these thermosetting, strong, rigid and brittle polycondensation resins against hydrolysis has been significantly increased in comparison with UF resin alone (Marutzky R., 1994; Paiva *et al.,* 2012; Brunner *et al.,* 2010). In such amino resins, which require a suitable acid hardener, the formaldehyde reacts with urea and melamine monomers to form quasi-linear polymer chains (Pizzi and Mittal, 2003).

In general, adhesive manufacturer recommendation for adhesives say that the highest bonding strength are reach with the maximum 2% difference in MC between bonded boards. Recommended MC of wood for bonding is 6–8%, but for PUR adhesives reactive with water in adhesive it can be a little bit higher and there is also recommendation of spraying water before applying of PUR adhesives. Purpose of this study is to compare bonding quality of different adhesives on hardwood species with different MC conditions of the boards.

MATERIALS AND METHODS

Specimen Preparation

Two species of wood, European beech (*Fagus sylvatica L.*) and English oak (*Quercus robur L.*) were used for boards manufacturing in this study. Density of beech was 719 ± 37 kg/m^3 and oak 629 ± 29 kg/m^3. The dimension of specimen used was 11 × 45 × 600 mm (thickness × width × length) and range of grain angles was between 30° and 60°. The boards were oven-dried and then the weight was recorded. Afterward, boards were sorted into three target final MC groups (6, 10 and 14%), each group was conditioned separately. All boards were conditioned to their respective target MC in accordance with the temperature-relative humidity diagram reported by Kollmann and Côté (1968).

I: *Comparison of target MC with real MC of the beech and oak boards*

Target MC	Beech MC [%]	Oak MC [%]
6	5.2 (0.3)	4.0 (0.4)
10	11.0 (0.1)	9.9 (0.6)
14	13.3 (0.2)	11.0 (1.0)

Numbers in parentheses represent standard deviation

The specimens were conditioned in a climate-controlled environmental chamber, the Memmert CTC 256 (Memmert GmbH + Co. kg, Schwabach, Germany) which was gravimetrically controlled until the specimen maintained a constant weight. An average MC of both species is listed in Tab. I.

Applied Adhesives

Specimens were bonded together with seven different adhesives: PVAC (Technobond D3, Technobond 1KD4, Multibond SK-8, Nexo D3), PUR (Neopur 2238), UF (Protodur 303.0) a MUF (Danafix 458 with hardener H-5108). UF resin was procured with a 2:1 ratio of adhesive and water, respectively. Regarding MUF (Danafix 458 with hardener H-5108), the mixing ratio was 10:2 of adhesive and hardener, respectively.

Manufacturing

After conditioning, the bonding surface of each board was planed to the final thickness of 10 mm. Boards were bonded together utilizing two combinations of MC: 10% to 10% (control) and 6% to 14% (different MC). Control and different MC groups were achieved in both species. Specimens were bonded using seven different adhesives mentioned above. In order to mitigate surface deactivation of the substrate, each board was bonded no later than 12 hours after planing; this practice is recommended by adhesive manufacturers. The adhesive was spread on one surface. Bonding of specimens was accomplished in a laboratory grade press HL 400 MENDELU (Strozatech, Brno, Czech Republic). The amount of adhesive and the pressing parameters were set according to each adhesive manufacturer´s recommendations (Tab. II). After pressing, specimens were conditioned at 20°C and 65% RH until they reached equilibrium MC. Following specimens conditioning, they were cut to geometries in accordance with EN 13354, standard for bonding quality. Each group contained 22 test specimens, yielding a total of 616.

Testing Procedures

Testing was performed utilizing a Zwick®Z050 universal testing machine with testXpert v11.02 software and a loadcell with a 50kN capacity (Zwick GmbH & Co. kg, Ulm, Germany). Testing of bonding quality was evaluated according to EN 13354.

II: *Adhesive spread and pressing parameters for each adhesive*

Adhesive	Manufacturer identification	Spread rate [g/m²]	Press time [s]	Pressure [MPa]	Temperature [°C]
PVAc-1	Technobond D3	180	1800	1	20
PVAc-2	Technobond 1KD4	180	1800	1	20
PVAc-3	Multibond SK-8	200	1800	1	20
PVAc-4	Nexo D3	200	1800	1	20
PUR	Neopur 2238	200	5400	1	20
UF	Protodur 303.0	150	480	1	105
MUF	Danafix 458 (Hardener H-5108)	150	480	1	105

Statistical Analysis

The data were processed in STATISTICA 10 software (StatSoft Inc., USA) and evaluated using a one-factor analysis of variance (ANOVA), completed with Tukey's honest significance test (HSD test).

RESULTS AND DISCUSSION

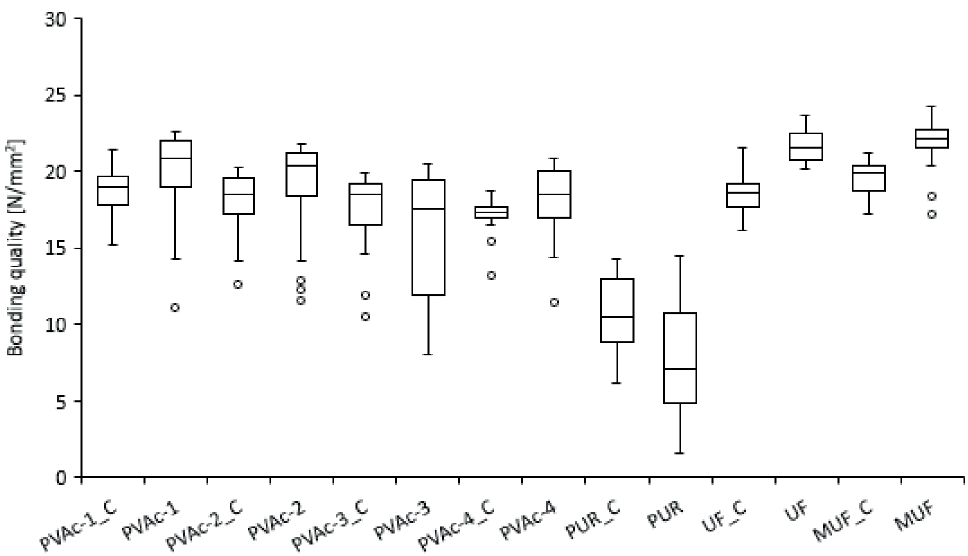
There were no statistically significant differences observed on beech wood specimens between PUR and UF adhesives. When utilizing PUR adhesive, the bonding quality was decreased (Fig. 1). The control sample was observed to have 10.7 N/mm² and sample with different MC had 7.8 N/mm² as presented in Tab. III. Decrease in bonding quality can be caused by the poor penetration of the adhesive or poor chemical reaction of PUR adhesive, due to low MC in the wood. It is well known that PUR adhesives need water for their bonding potential (Pizzi and Mittal 2003). Significant increase of the bonding quality was observed in the UF adhesive. The control sample was observed to be 18.5 N/mm² and sample with different MC had 21.6 N/mm². Within PUR and UF adhesives, there is no statistically difference of bonding quality observed on beech wood specimens.

There was observed a trend in increased bonding quality of PVAc adhesives (Fig. 2), as well as oak specimens with MC that differ from the control.

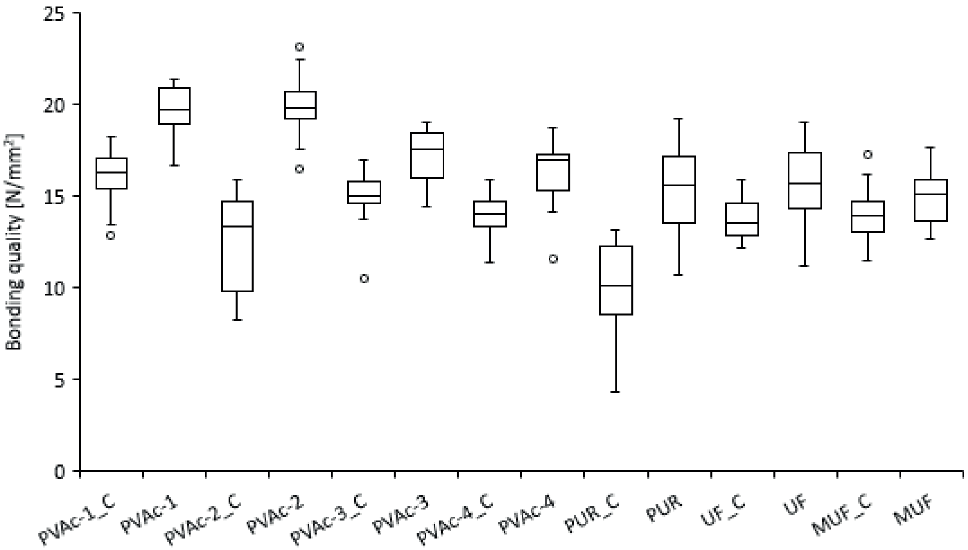
III: *Average bonding quality of beech for control and different MC specimens*

	Bonding quality of control [N/mm²]	Bonding quality of different MC [N/mm²]
PVAc-1	18.8 (1.4) D, E	20.0 (3.1) E, F
PVAc-2	17.8 (2.3) C, D, E	19.0 (3.3) D, E
PVAc-3	17.5 (2.6) C, D, E	16.1 (4.3) C
PVAc-4	17.2 (1.2) C, D	18.1 (2.3) C, D, E
PUR	10.7 (2.4) B	7.8 (3.8) A
UF	18.5 (1.4) C, D, E	21.6 (1.0) F
MUF	19.6 (1.1) D, E, F	21.9 (1.7) F

Means with the same letter in column do not differ statistically, according to the Tukey´s test (α = 0.05). Numbers in parentheses represent standard deviation



1: *Bonding quality of beech; C-Control specimens (10/10% MC), without mark-Different MC (6/14%) of specimen*



2: *Bonding quality of oak; C-Control specimens (10/10% MC), without mark-Different MC (6/14%) of specimen*

This increase is statistically significant for adhesives employed in oak. Increase can be caused by the better penetration or flow of adhesives to the wood structure. The highest increase was observed for PUR adhesive about 5.4 N/mm^2 between the control and 6/14% MC specimens (Tab. IV). This trend was contrary to the trend observed on beech wood. It can be caused by the wood species, different structure of the oak wood. There was also lower MC of the oak specimens before bonding Tab. I. Especially for PUR adhesive the difference in MC can cause better reaction of isocyanate with moisture for forming the bondline. Statistically significant increase was also observed on UF adhesive. The same trend like on beech was observed on MUF adhesive on oak specimens with no changes in bonding quality.

IV: *Average bonding quality of oak for control and different MC specimens*

	Bonding quality of control [N/mm^2]	Bonding quality of different MC [N/mm^2]
PVAc-1	16.1 (1.3) E, F	19.5 (1.9) G
PVAc-2	12.5 (2.6) B	19.8 (1.6) G
PVAc-3	14.9 (1.3) C, D, E	17.0 (2.0) F
PVAc-4	14.0 (1.0) B, C, D	16.3 (1.7) E, F
PUR	9.9 (2.5) A	15.3 (2.4) C, D, E, F
UF	13.7 (1.0) B, C	15.7 (2.0) D, E, F
MUF	14.1 (1.6) B, C, D	14.9 (1.4) C, D, E

Means with the same letter in column do not differ statistically, according to the Tukey´s test ($\alpha = 0.05$). Numbers in parentheses represent standard deviation

CONCLUSION

The comparison of the bonding quality of different adhesives on two hardwood species showed different trends. All four PVAc adhesives showed the same trend on each wood specie. There was not a statistically significant difference for PVAc adhesives on beech wood but there was significant increase for different MC specimens on oak. PUR on beech wood showed significant decrease, on oak wood significant increase for specimens bonded with different MC in compare to control specimens. For UF resin was observed increase on beech and oak wood bonded in different MC. MUF resin had consistent results without any significant change on both wood species.

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REFERENCES

BEKHTA, P., ORTYNSKA, G. and SEDLIACIK, J. 2014. Properties of Modified Phenol-Formaldehyde Adhesive for Plywood Panels Manufactured from High Moisture Content Veneer. *Drvna industrija*, 65(4): 293–301.

BRUNNER, M., LEHMANN, M., KRAFT, S., FANKHAUSER, U., RICHTER, K. and CONZETT, J. 2010. A Flexible Adhesive Layer to Strengthen Glulam Beams. *Journal of Adhesion Science and Technology*, 24(8–10): 1665–1701.

CREMONINI, C. and PIZZI, A. 1999. Field weathering of plywood panels bonded with UF adhesives and low proportions of melamine salts. *Holz als Roh- und Werkstoff*, 57(5): 318–318.

DUNKY, M. 1998. Urea–formaldehyde (UF) adhesive resins for wood. *International Journal of Adhesion and Adhesives*, 18(2): 95–107.

DUNKY, M. and NIEMZ, P. 2002. *Holzwerkstoffe und Leime*. Berlin, Heidelberg: Springer Berlin Heidelberg.

HABENICHT, G. 2006. *Kleben: Grundlagen, Technologien, Anwendungen*, Berlin, Heidelberg: VDI-Buch, Springer-Verlag.

KOLLMANN, F. F. and CÔTÉ, W. A. 1968. Principles of Wood Science and Technology I Solid Wood. In: *Principles of Wood Science and Technology*. New York: Springer-Verlag.

MARUTZKY, R. 1994. Release of formaldehyde by wood products. In: PIZZI, A. and DEKKAR, M. (Eds.). *Wood adhesives-chemistry and technology*. New York and Basel: Marcel Dekker Inc.

PAIVA, N. T., HENRIQUES, A., CRUZ, P., FERRA, J. M., CARVALHO, L. H. and MAGALHÃES, F. D. 2012. Production of melamine fortified urea-formaldehyde resins with low formaldehyde emission. *Journal of Applied Polymer Science*, 124(3): 2311–2317.

PIZZI, A. and MITTAL, K. 2003. *Handbook of Adhesive Technology*. CRC Press.

VICK, C. B. 1999. Adhesive bonding of wood materials. In: *Wood handbook— wood as an engineering material*. US Department of Agriculture, Forest Service. Madison, WI: Forest Products Laboratory.

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