doi: 10.17221/8/2014-RAE

Bonding of wood

M. Brožek

Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Prague, Czech Republic

Abstract

Brožek M. (2015): **Bonding of wood**. Res. Agr. Eng., 61: 134–139.

The paper presents the results of strength tests of joints made using six different adhesives destined by their producers for bonding wood. Bonded samples were made from seven sorts of wood commonly growing in the Czech Republic, namely ash, beach, cherry, maple, pine, spruce and walnut. From semi-products (boards, planks, squared timber logs) the test samples of dimensions 25 × 100 mm and 4 mm thickness were cut out in the direction of year rings. Always two samples were bonded together so that their overlap was of 12.5 mm. All these assemblies were loaded using the universal testing machine up to their rupture. The rupture force and the rupture type (rupture in the joint, in the bonded material) were registered. The aim of the tests was to assess the influence of the used adhesive on the bonded joint strength at different woods, to assess the variability of the adhesive consumption at the manual adhesive application by different workers and to determine costs for bonding of different woods using different adhesives. From the results it follows that between six tested adhesives used for bonding of seven sorts of wood, considerable differences exist not only as regards their price, but also their quality. From the results it also follows that the manual adhesive application is very unequal, because it depends on the dexterity and care of the worker. Next, the costs for bonding of different woods using different adhesives were determined.

Keywords: adhesive bonding; laboratory tests; bonded joints testing

The technical level increase in the field of bonding of classic as well of modern materials in the second half of the last century led to the rapid development of synthetic adhesives, binders and cements production and concurrently to the technology development, which enables their economical use. Bonding is taken for modern and perspective method of undetachable jointing of metallic and non-metallic materials.

Just as other technologies adhesive bonding is distinguished by many advantages, but by some negative and limiting factors, too. By the determining of the bonded joint type it is necessary, except for the economical point of view, to consider not only advantages, but also disadvantages of bonding technology compared with conventional bonding ways, e.g. welding (surfacing) (Brožek 2007), soldering (Brožek 2013b,c), riveting, and screwing. It is necessary to consider adhesive bonding as a supplement to the above-mentioned methods, not as their substitution.

For the successful application of adhesives in practice the good knowledge of the bonding technology and of the used adhesives tecWhnological properties is important. The final quality of the bonded joint is actually influenced by many factors.

Supported by the Internal Grant Agency of the Czech University of Life Sciences Prague, Prague, Czech Republic; Project No. 2014:31140/1312/3133.

doi: 10.17221/8/2014-RAE

Except for the suitable design of the bonded joint and choice of an adhesive suitable for the concrete material, it is above all the careful preparation of bonded surfaces. However, the adhesive layer thickness (actually the glue joint between two bonded surfaces), roughness of adherents, load type (static or dynamic) and direction (radial, axial), way of curing, operation conditions of the bonded structure etc. (Epstein 1954; Cagle 1973; Loctite 1988; Pizzi, Mittal 2003; Ebnesajjad 2008, Brožek 2013a,d; Brožek et al. 2014) have the substantial influence on the bonded joint final strength.

In this paper we concentrate on adhesive bonding of wood. Wood is a natural material, which our ancient ancestors have learned to utilize very early. The first use of wood was evidently energy utilization with the aim to gain heat by its combustion. Later, wood was used for construction of buildings and fortifications, means of transport (ships and wagons) and tools.

In contrast to other materials (metals, plastics, aggregate, limestone, glass, ceramics) wood has one exceptional advantage – it is a renewable material. From statistical sources it follows that in the Czech Republic the one-year wood growth is in the long term higher than logging. So the wood supplies increase.

Compared to other materials the properties of wood are different (Kafka 1989; Pluhař et al. 1989; Peschel 2002; Kettunen 2006). Some differences can be seen at first sight, e.g. colour, gleam or texture. In contrast to many other materials wood has a specific aroma. From physical properties let us specify e.g. density, moisture (shrinkage, swelling) and thermal, electric and acoustic properties. From mechanical properties at least elasticity, strength (tensile, pressure, bending, shear, torsion), hardness, toughness are specified. Technological properties of wood are also exceptional, e.g. machinability, bendability, loading capacity of metallic binders, wear resistance or various defects.

Even today wood is considered to be a very good building material. The greatest consumer of wood is therefore building industry, followed by cellulose-paper industry (Tsoumis 1991; Faherty, Williamson 1995; Zahradníček, Horák 2007; Slavid 2009). Production of furniture, musical instruments, artworks, sports equipment or toys for children represents an interesting utilization of wood. A part of wood is consumed in form of firewood.

Bonding of wood is no doubt the topical technical problem, which many authors are engaging in from different angles of view. Hiziroglu et al. (2014) studied the influence of wood surface roughness on bonded joint strength. Voulgaridis et al. (2012) and Iwakiri et al. (2013) researched strength of joints bonded using various adhesives. Stoeckel et al. (2013) published the summary of factors influencing the final bonded joint strength. D'Amico et al. (2012) studied the influence of adhesive ageing on bonded joints strength. Uysal et al. (2010) and Fecht et al. (2014) studied the bonded joint strength related to temperature and time.

Current topic is e.g. production of plywood. Many authors dealt with it from different aspects. Sellers (1989), Olivares and Sellers (1994), Chen (1995), Yang et al. (2006), Cheng and Wang (2011), Garcia Esteban et al. (2011), and He et al. (2012) engaged intimately in the issues of plywood production in production plants, in research and development of adhesives new types or in plywood properties.

Nováková and Brožek (2009) engaged in pine plywood bonding using fusible adhesives. They proved that the final strength influences at most the angel of specimens cutting out from a semi-product (lengthwise, angle 0°, in the inclined direction, angle 45°; or crosswise, angle 90°. At the same time they proved that the joints bonded using different fusible adhesives show different load capacity and that the influence of surface roughness is relatively small.

Brozek (2013d) occupied with similar problems. In the contribution the methodology of technical-economical evaluation of tested adhesives and of bonded joints was published and checked. At the same time it was proved that between adhesives offered in the domestic market considerable differences exist. That is both in their price and in their quality, evaluated according to the bonded joint strength.

MATERIAL AND METHODS

For the tests six types of domestic as well as foreign adhesives were bought (Table 1). For the bonded joints strength testing using different woods the test according to the modified standard CSN EN 1465 (66 8510):1997 (Adhesives – the determination of the tensile lap-shear strength of rigid-torigid bonded assembilies) adhesives were used. For these tests woods growing in the Czech Republic, namely ash, beech, cherry, maple, pine, spruce and walnut were used.

The test samples of size 100 × 25 mm and 4 mm thickness were cut out from semi-products (boards, planks, squared logs) in the direction of

doi: 10.17221/8/2014-RAE

Table 1. Tested adhesives

Adhesive	Designation	Symbol on packing	Producer/supplier	Chemical nature	Weight/packing (g)	Price/packing (CZK)	Price/adhesive (CZK/g)
1	DB	Den Braven Zwaluw super glue	Den Braven Czech and Slovak, a.s.	cyanoacrylate	3	7.5	2.50
2	D2	Den Braven wood glue D2	Den Braven Czech and Slovak, a.s.	dispersive	250	43	0.17
3	HE	Herkules univerzální lepidlo	Druchema	dispersive	250	54	0.22
4	10	1001U Tectane sekundové lepidlo	Den Braven Czech and Slovak, a.s.	cyanoacrylate	20	81	4.05
5	PA	Pattex 100%	Henkel ČR s r. o.	silane cross-linked polymer	100	154	1.54
6	UH	UHU contact	UHU GmbH & Co. KG	polyurethane	20	49	2.45

exchange rate at 07. 02. 2014: 1 EUR = 27.500 CZK

their length. Form and dimensions of samples before and after bonding are evident from Fig. 1.

The bonding was carried out according to the recommendation of the relevant adhesive producer. The adhesive was applied manually by different workers. From each adhesive type 12 bonded assemblies were tested. The amount of the adhesive needed for bonding of each run was determined. The total made more than 500 bonded joints.

After the adhesive curing (min. 24 h) the bonded samples were fixed in jaws of a tensile-strength testing machine and loaded till to the rupture (in the bond, in the bonded material).

The rupture force F was determined. Then the overlapping width b and overlapping length l of each tested assembly were measured. From these values the bonded joint surface S was calculated:

$$S = b \times l \quad (1)$$

where:

S – bonded joint surface (mm^2)

b – overlapping width (mm)

l – overlapping length (mm)

The tensile lap-shear strength τ of the bonded assembly was calculated using the equation:

$$\tau = F/S \quad (2)$$

where:

τ – tensile lap-shear strength (MPa)

F – rupture force (N)

S – bonded joint surface (mm^2)

The aim the tests was to evaluate the influence of the sort of used wood on the bonded joint strength, to assess the variability of adhesive consumption at the manual application by different workers and to determine costs for bonding of different woods using different adhesives.

RESULTS AND DISCUSSION

The laboratory tests results of bonded joints strength for samples made from different woods and bonded using different adhesives are presented in Fig. 2. The joints rupture occurred either in the bonded surface or in the bonded material.

From Fig. 2 it follows that the relatively favourable results were achieved using both Den Braven adhesives (Den Braven, Oosterhout, The Netherlands),

doi: 10.17221/8/2014-RAE

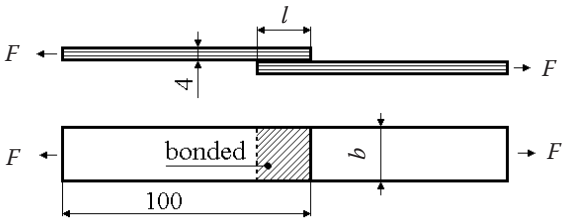

Fig. 1. Size of test samples
F – rupture force; *l* – overlapping lenght; *b* – overlapping width

the Herkules (Druchema družstvo, Prague, Czech Republic) adhesive and the 1001 U Tectane adhesive (Den Braven, Oosterhout, The Netherlands). The bonded joints strength ranged from 6.6 to 14.0 MPa. Using Pattex 100% (Henkel, Düsseldorf, Germany) and UHU Contact adhesives (UHU GmbH & Co. KG, Bühl, Germany) the joints strength was very low and therefore these adhesives cannot be recommended even when their producers declare that they are usable for bonding of wood. The strength of bonded joints using the Pattex 100% adhesive was only from 1.4 to 2.2 M Pa, using the UHU Contact adhesive it was even lower, namely from 0.3 to 1.2 MPa.

The best results were reached using both quick-setting adhesives. Using Den Braven Zwaluw super glue, about 53% of joints ruptured in the bonds (the rest 47% ruptured in the used material), using 1001 U Tectane it was 64%. At the disperse adhesives the failure in the bond occurred in about 82% causes (Herkules). From this point of view the adhesives Pattex 100% and UHU Contact were unsuitable. Using both these adhesives all joints ruptured in bonds already at a very low load.

From the point of view of the tested woods the highest strength showed beech, when 97% of the tested samples ruptured in the bonds and only 3% ruptured in the wood. The strength of woods decreased in order maple (8% joints ruptured in the wood), ash (10%), walnut (about 18%), spruce (about 27%), pine (about 32%) and cherry (about 39%).

The relation between the bonded joint strength and the bonded joint price for the adhesive Den Braven Zwaluw super glue (cyanoacrylate) can be seen in Fig. 3a, for Den Braven D2 (dispersive) in Fig. 3b, for Herkules universal adhesive (dispersive) in Fig. 3c and for 1001 U Tectane quick setting adhesive (cyanoacrylate) in Fig. 3d.

The differences between prices of the tested adhesives are great (Table 1). The most expensive tested adhesive (1001 U, cyanoacrylate super glue) was almost 24 times more expensive than the cheapest one (Den Braven, wood glue D2).

From the technical-economical point of view the most advantageous and so the strongest and at the same time the cheapest bonded joints are in the picture left on the top (Fig 3). On the contrary, the most expensive and the least strong joints are right at the bottom.

The tested samples were bonded by six different workers, when each from them adhered by one type of adhesive the samples from all seven tested woods. With regard to the different price of the tested adhesives (Table 1) and their consumption it is not possible to compare directly among them the costs of joints using different adhesives. It is necessary to assess individually the joints made by one adhesive type and by one worker always for all seven tested woods. At the tests each worker made 84 joints. From the comparison expressed by the variation coefficient, it is evident that with the manual application the equal adherent amount at all joints is very difficult to keep. At joints made by four workers the value of the variation coefficient ranged from 11.1% to 14.5%. At one worker the low value of the variation coefficient was 4.6%, on the contrary at another one the high value (17.4%) was determined.

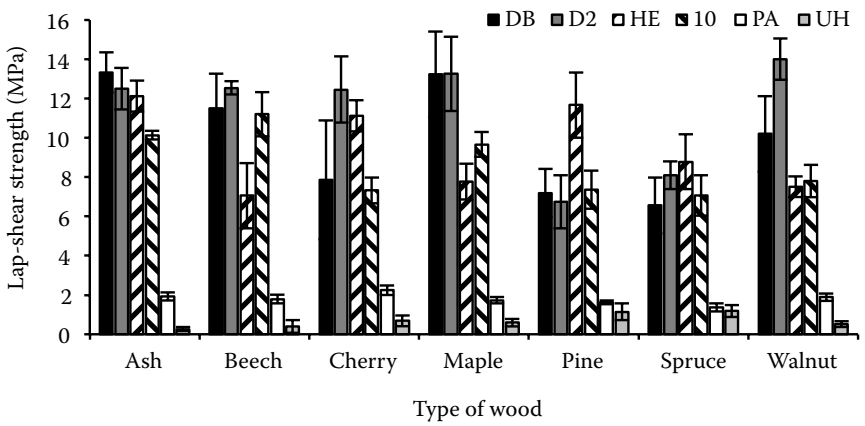

Fig. 2. Test results of the wooden samples

doi: 10.17221/8/2014-RAE

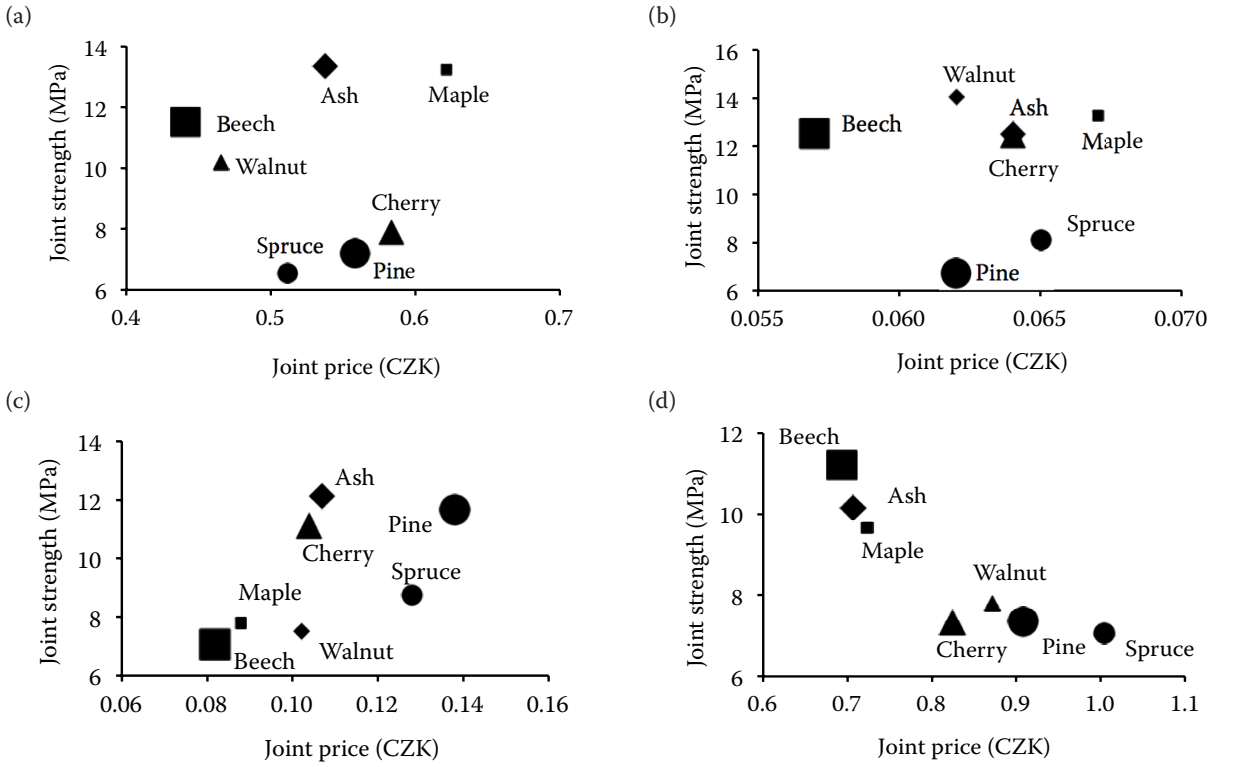

Fig. 3. Relation between the bonded joint strength and the joint price (a) Den Braven Zwaluw super glue (cyanoacrylate), (b) Den Braven wood glue D2 (dispersive), (c) Herkules universal adhesive (dispersive) and (d) 1001 U Tectane super glue (cyanoacrylate)

CONCLUSION

The paper presents the results of strength test of joints made carried out using six different adhesives which were destined by their producers for bonding of wood. The adhesive prices ranged in a relatively wide extent between 0.17 and 4.05 CZK/g.

The bonded samples were made from seven sorts of wood (ash, beech, cherry, maple, pine, spruce and walnut) commonly growing in the Czech Republic. The bonding was made exactly according to the producers' recommendations. The amount of the adhesive needed for the bonding of each run was determined.

From bought semi-products (boards, planks or squared timber logs) the test samples of size 25 × 100 mm and 4 mm thickness were cut out in longitudinal direction. Two samples were always adhered together at the overlap of 12.5 mm. After bonding the assemblies were left in a laboratory till to the adhesive total curing (min. 24 h). The specimens were loaded using the universal testing machine till the rupture and the max. force was noted. The tests were carried out according to the modified standard CSN EN 1465 (66 8510):1997.

The part of the evaluation was the assessment of the samples after the test. The joint rupture occurred either in the adhesive layer or in the basic material.

From the carried out tests, it follows that the manual application of the adhesive is very unequal. The amount and unequal distribution of the adhesive depends on the dexterity and evidently on the care of the worker.

For adhesive bonding of wood four from six tested adhesives can be recommended, namely both types of the adhesives Den Braven, the adhesive Herkules and the adhesive 1001 U Tectane. The adhesives Pattex 100% and UHU Contact cannot be recommended for bonding of wood. Joints bonded using these two adhesives have a very low value of strength.

In the contribution, the methodology of the technical-economical evaluation of the tested adhesives and of bonded joints was published and checked. At the same time it was proved that between adhesives offered in the domestic market considerable differences exist, both in their price and in their quality, as evaluated according to the bonded joint strength.

doi: 10.17221/8/2014-RAE

References

Brožek M. (2007): Technicko-ekonomické hodnocení aplikace návarů u plužních čepelí. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 55: 129–136.

Brožek M. (2013a): Optimization of adhesive layer thickness at metal bonding using quick-setting adhesives. Manufacturing Technology, 13: 419–423.

Brožek M. (2013b): Soldering sheets using soft solders. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 61: 1597–1604.

Brožek M. (2013c): Soldering steel sheets using soft solder. Research in Agriculture Engineering, 59: 141–146.

Brožek M. (2013d): Technical-economical evaluation of plywood bonding. In: 5th International Conference Trends in Agricultural Engineering. Sept. 3–6, 2013. Prague, Czech University of Life Sciences Prague: 100–105.

Brožek M. (2014): Technical-economical evaluation of beech plywood bonding. In.: 13th International Scientific Conference Engineering for Rural Development. May 29–30, 2014. Jelgava, Latvia University of Agriculture: 168–173.

Cagle Ch.V. (1973): Handbook of Adhesive Bonding. New York, McGraw-Hill.

Chen C.M. (1995): Gluability of Kraft lignin copolymer resins on bonding southern pine plywood. Holzforschung, 49: 153–157.

Cheng R.X., Wang Q.W. (2011): The Influence of FRW-1 fire retardant treatment on the bonding of plywood. Journal of Adhesion Science and Technology, 25: 1715–1724.

D'Amico S., Hrabalova M., Muller U., Berghofer E. (2012): Influence of ageing on mechanical properties of wood to wood bonding with wheat flour glue. European Journal of Wood and Wood Production, 70: 679–688.

Ebnesajjad S. (2008): Adhesives Technology Handbook. 2nd Ed. Norwich, William Andrew.

Epstein G. (1954): Adhesive Bonding of Metals. New York, Reinhold.

Faherty K.F., Williamson T.G. (1995): Wood Engineering and Construction Handbook. 2nd Ed. New York: Osborne-McGraw-Hill.

Fecht S., Vallée T., Tannert T., Fricke H. (2014): Adhesively bonded hardwood joints under room temperature and elevated temperatures. Journal of Adhesion, 90: 401–419.

Garcia Esteban L., Garcia Fernandez F., de Palacios P. (2011): Prediction of plywood bonding quality using an artificial neural network. Holzforschung, 65: 209–214.

He G., Feng M., Dai C., (2012): Development of soy-based adhesives for the manufacture of wood composite products. Holzforschung, 66: 857–862.

Hiziroglu S., Zhong Z.W., Ong W.K. (2014): Evaluating of bonding strength of pine, oak and nyatoh wood species related to their surface roughness. Measurement, 49: 397–400.

Iwakir S., Trianoski R., da Cunha A.B., Prata J.G., Hara M., Bila N.F., Guina R.C.G., de Araújo R.D., Bôas B.T.V. (2013): Evaluation of the strength of wood bonded joints of *Eucalyptus benthamii* glued with different adhesives and gluing surfaces. Scientia Forestalis, 41: 411–416.

Kafka E. (1989): Dřevařská příručka. 1st Ed. Prague, Nakladatelství technické literatury.

Kettunen P.O. (2006): Wood: Structure and Properties. Uetikon-Zuerich; Enfield, Trans Tech Publication.

Loctite (1988): Der Loctite. München, Loctite.

Nováková A., Brožek M. (2009): Bonding of non-metallic materials using thermoplastic adhesives. In: 8th International Scientific Conference Engineering for Rural Development. May 28–29, 2009, Jelgava, Latvia University of Agriculture: 261–264.

Olivares M., Sellers T. (1994): Resin-adhesive formulations for bonding exterior-type plywood using chilean radiata pine and 4 hardwoods. Holzforschung, 48: 157–162.

Peschel P. (2002): Dřevařská příručka. Tabulky. Technické údaje. Prague, Sobotáles.

Pizzi A., Mittal K.L., 2003. Handbook of Adhesive Technology. New York, Dekker.

Pluhař J. et al. (1989): Nauka o materiálech. Prague, SNTL.

Sellers T. (1989): Diisocyanate furfural adhesive for bonding plywood. Forest Production Journal. 39: 53–56.

Slavid R. (2009): Wood Architecture. Paperback Ed. London, Laurence King.

Stoeckel F., Konnerth J., Gindl-Altmutter W. (2013): Mechanical properties of adhesives for bonding wood-A review. International Journal of Adhesion and Adhesives, 45: 32–41.

Tsoumis G. (1991): Science and technology of wood: Structure, properties, utilization. New York, Chapman & Hall.

Uysal B., Kurt S., Yildirim M.N. (2010): Bonding strength of wood materials bonded with different adhesive after aging test. Construction and Building Materials, 24: 2628–2632.

Voulgaridis E., Passialis C., Negri M., Adamopoulos S. (2012): Shear bond strength of black locust wood glued with three adhesive systems. Wood Research, 57: 489–496.

Yang I., Kuo M., Myers D. J. (2006): Bond quality of soy-based phenolic adhesives in southern pine plywood. Journal of the American Oil Chemists' Society, 83: 231–237.

Zahradníček V., Horák P. (2007): Moderní dřevostavby. 1st Ed. Brno, ERA.

Received for publication March 31, 2014
Accepted after correction September 17, 2014

Corresponding author:

Prof. Ing. Milan Brožek, CSc., Czech University of Life Sciences Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, Kamýcká 129, 165 21 Praha 6-Suchdol, Czech Republic
phone: + 420 224 383 265, fax: + 420 234 381 828, e-mail: brozek@tf.czu.cz