TECHNICAL-ECONOMICAL EVALUATION OF BEECH PLYWOOD BONDING

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Abstract. The contribution contains results of bonded joints strength tests. The tests were carried out according to the modified standard CSN EN 1465 (66 8510). For bonding the beech three-ply wood of 4 mm thickness was used (according to CSN EN 636). The test samples of 100x25 mm size were cut out from a semi-product of 2500x1250 mm size in the direction of its longer side (incline 0º), in the inclined direction (incline 45º) and in the direction of its shorter side (crosswise - incline 90º). The bonding was carried out using seven different domestic as well as foreign adhesives according to the technology prescribed by the producer. All used adhesives were designated for wood bonding. At the bonding the consumption of the adhesive was determined. After curing the bonded assemblies were loaded using a universal tensile-strength testing machine up to the rupture. The rupture force and the rupture type were registered. Finally the technical-economical evaluation of the experiments was executed.

Keywords: bonding, adhesive, bonded joints testing, costs of bonding.

Introduction

Increase in a technical level in the field of bonding of classic as well of modern materials led in the second half of the last century to the synthetic adhesives, binders and cements production rapid development and concurrently to the technology development, which enables their economical use.

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 weigh not only advantages, but also disadvantages of bonding technology compared with conventional bonding ways, e.g. welding [1; 2], soldering [3; 4], riveting, and screwing. It is necessary to consider adhesive bonding for supplement of about mentioned methods, not for their substitution.

For the successful application of adhesives in practice the good knowledge of the bonding technology and of the used adhesives technological properties are important. The final quality of the bonded joint is actually influenced by many factors. Except for the bonded joint suitable design and the suitable adhesive choice for the concrete material it is above all the careful preparation of bonded surfaces. But the adhesive layer thickness (actually the glue joint between two bonded surfaces), roughness of adherends, load type (static or dynamic) and direction (radial, axial), way of curing, operation conditions of bonded structure etc. [5-10] have the substantial influence on the bonded joint final strength.

In present bonding of plywood is still very topical. Many authors look at it from different view angles. Authors [11-18] engaged intimately in the issues of plywood production in production plants, in research and development of adhesives new types or in plywood properties.

Authors [19] and [20] engaged in pine plywood bonding using adhesives. They proved that the final strength influences at most the angel of samples cutting out from a semi-product (lengthwise, angle 0º, in the inclined direction, angle 45º or crosswise, angle 90º. 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.

Materials and methods

For the tests seven types of domestic as well as foreign adhesives were bought (Table 1).

Test samples were cut out from a three-ply plywood sheet (according CSN EN 636) [21] of size 2500x1250 mm and of 4 mm thickness in different directions – in the direction of the longer semi-product size (incline 0º), in the direction of the shorter semi-product size (incline 90º) and in the inclined direction (incline 45º). Plywood was chosen because it is easily accessible and universally applicable material of low price.

For strength testing of plywood joints the test according to the modified standard CSN EN 1465 (66 8510) [22] was used. The bonded assembly is evident from Fig. 1 (b = 20 mm, l = 12.5 mm).

Table 1

Summary of tested adhesives

Adhesive	**Designation in text**	**Adhesive symbol on the wrapping**	**Producer/supplier of the adhesive**
1	10	1001U, sekundové lepidlo (super glue)	Den Braven Czech and Slovak, a.s.
2	DB	Den Braven, super glue	Den Braven Czech and Slovak, a.s.
3	D2	Lepidlo na dřevo D2 (wood glue)	Den Braven Czech and Slovak, a.s.
4	PR	Pritt, gamafix bílý (gamafix white)	Henkel ČR, spol. s r. o.
5	PW	Pattex Wood Standard	Henkel ČR, spol. s r. o.
6	HE	Herkules, univerzální lepidlo (universal glue)	Druchema družstvo
7	PA	Pattex 100 %	Henkel ČR, spol. s r. o.
Adhesive	**Amount of the wrapping, g**	**Price of the wrapping, CZK**	**Price of the adhesive, CZK·g^{-1}**
1	20	81.00	4.05
2	3	7.50	2.50
3	250	43.00	0,17
4	100	44.00	0.44
5	250	125.00	0.50
6	250	54.00	0.22
7	100	154.00	1.54

Notes:

1. Index 0, 45 or 90 at the designation denotes the direction of the cutting out from a semi-product (lengthwise, in the inclined direction, crosswise).
2. For information: Exchange rate at 14.02.2014: 1 € = 25.435 CZK (http://www.kurzy.cz/kurzy-men/historie/ceska-narodni-banka/)

The bonding (at a pressure of 1.1 MPa and a temperature of 22±2 °C) was carried out according to the recommendation of the relevant adhesive producer. From each adhesive type and from each direction of samples cutting out from a semi-product 12 bonded assemblies were tested. The amount of the adhesive needed for the bonding of each run was determined (see data in Table 1 and Fig. 3).

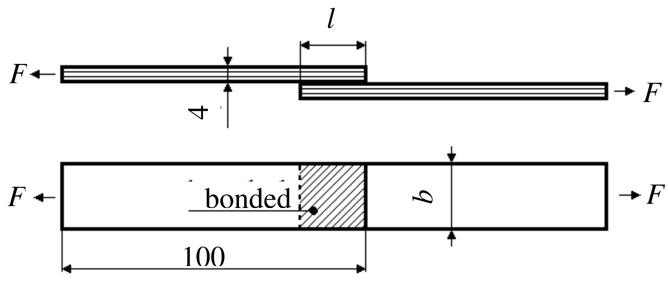

Fig. 1. **Tested assembly consisting of two bonded samples**

After the adhesive curing (min. 24 hours) the prepared bonded samples were fixed in jaws of a tensile-strength testing machine and loaded till to the rupture. The rupture force *F* (N) was determined. Then the overlapping width *b* (mm) and overlapping length *l* (mm) of each tested assembly were measured. From these values the bonded joint surface *S* (mm^2) was calculated

$$S = b \cdot l \tag{1}$$

where S – bonded joint surface, mm^2;

b – overlapping width, mm;
l – overlapping length, mm.

The tensile lap-shear strength of the bonded assembly (MPa) was calculated using the equation

$$\tau = \frac{F}{S} \quad (2)$$

where τ – tensile lap-shear strength, MPa,
F – rupture force, N,
S – bonded joint surface, mm^2.

The aim of carried out tests was to evaluate the influence of the load direction (0º, 45º and 90º) on the bonded joints load capacity using different adhesives and to determine the costs for bonding.

Results and discussion

The test results are presented in Figs. 2 and 3.

The joint rupture occurred either in the bonded surface or in the bonded material. The bonded joint was damaged mostly (83.3 %) at the samples cut out lengthwise (0º). At the samples cut out in the inclined direction (45º) the rupture occurred sometimes in the bonded joint (17.6 %), sometimes in the plywood (82.4 %). At the samples cut out crosswise (90º) the rupture occurred almost always (86.3 %) in the plywood.

The summary results of the samples cut out in the inclined direction of 45º and 90º are strongly influenced by the test results of the adhesive Pattex 100 %. At these bonded samples the anomaly occurred compared with the other adhesives results. The rupture in the bonded joint occurred identically in 11 of 12 tested joints. Only in one case at the directions 45º and 90º the joint ruptured in the bonded material (plywood).

If we will not consider the test results of joints bonded using the adhesive Pattex 100 % we discover that at the samples bonded using other adhesives and cut out lengthwise (0º) the rupture in the bonded joint occurred at 80.6 % of joints, at the samples cut out in the inclined direction (45º) at 5.8 % of joints and at the samples cut out crosswise (90º) only at 0.7 % of joints.

In Fig. 2 the adhesives are arranged from the highest strength to the lowest strength at the bonding of specimens cut out lengthwise from a semi-product (angle 0º). From the results it is evident that the load direction with regard to the plywood production influences the strength at most. In the longitudinal direction (0º) the joint rupture occurs in the adhesive layer, because the bonded material is more strong that the adhesive. On the contrary in next directions (45º and 90º) the plywood is less strong than the adhesive. From Fig. 2 it is evident that for different adhesives very different bonded joint strengths were determined. The highest strength in the lengthwise direction (0º) was determined at the adhesive 1001U super glue (10, 12.9 MPa). Gradually decreasing strength was determined at the adhesives Den Braven super glue (DB, 11.4 MPa), wood glue D2 (D2, 11.3 MPa), Pritt gamafix white (PR, 9.5 MPa), Pattex Wood Standard (PW, 9.4 MPa) and Herkules (HE, 7.7 MPa). The lowest joint strength was measured at the use of the adhesive Pattex 100 % (PA, 1.9 MPa).

In the longitudinal direction (0º) the strength values are not expressively influenced by the plywood strength. The ratio of the highest to the lowest strength is about 6.9.

In the inclined direction (45º) the order of joints strength was changed. It is caused by force of circumstance that the bonded joint strength is influenced by the strength of the used plywood. The highest joint strength was determined at the adhesives 1001U super glue and Pattex Wood Standard (10 and PW, 4.5 MPa). Next four adhesives (PR, D2, HE and DB) were showing the joint strength of about 4 MPa. The lowest strength was determined at the joints bonded using the adhesive Pattex 100 % (Pa, 2.1 MPa). The ratio of the highest to the lowest determined strength is about 2.2.

The lowest values of the bonded joints strength were determined at bonding of samples cut out crosswise (90º). The highest joints strength was determined at the use of the adhesives Pattex Wood Standard, wood glue D2 and Pritt gamafix white (PW, D2 and PR, 3.4 MPa), the lowest one at the use of the adhesive Pattex 100 % (PA. 1.8 MPa). The ratio of the highest to the lowest strength is about 1.4.

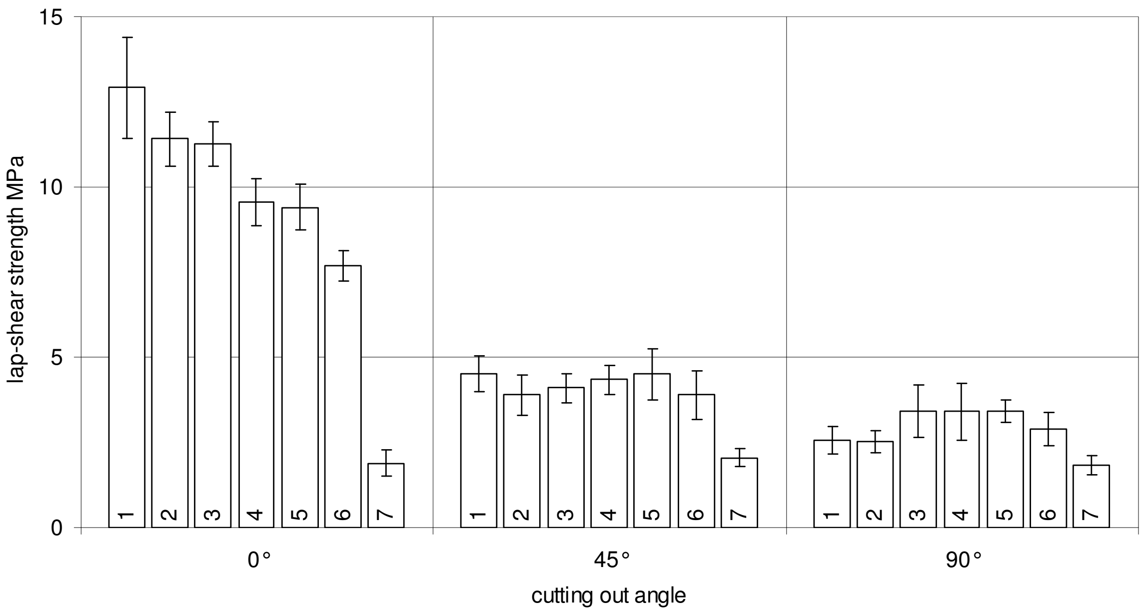

Fig. 2. **Relation between the tensile lap-shear strength and the cutting out angle**

From the statistical evaluation of the carried out tests it follows that the dispersion of values of the bonded joints strength (standard deviation) is relatively great.

The differences between prices of tested adhesives are very great (Tab. 1). The most expensive tested adhesive (1001U, 10) was approximately 23.5 times more expensive than the cheapest one wood glue D2. At the same time it was confirmed that joints bounded using the adhesive 1001U showed (for the direction 0º) the highest strength, although only of about 1.6 MPA, compared with the joint strength using the cheapest adhesive D2.

The graphical representation of strength and price of the bonded joint is shown in Fig. 3. For the problem analysis it is fit to describe the results separately for each tested direction (0º. 45º, 90º). The certain inaccuracies of joint prices result from the use of manual proportioning. 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. On the contrary, the most expensive and the least strong joints are right at the bottom.

For the direction 0º the wood glue D2 can be recommended. It shows the best ratio of quality (bonded joint strength) to price (in this case the strength of 11.3 MPa at costs 0.11 CZK for one joint). As suitable the adhesives marked DB, PR, PA and HE can be recommended. Joints bonded using these adhesives are keenly priced (from 0.11 to 0.34 CZK at the relatively high strength (from 7.7 to 11.4 MPa). The adhesive 1001U can be recommended only in the case when high joint strength is needed and the price is less significant. The adhesive Pattex 100 % cannot be recommended, because its strength is low and the joints are expensive.

For the direction 45º the considerable lower load capacity of bonded joints compared with the direction 0º was reached. Above all it is caused by the influence of the strength of the bonded material – beech plywood. The bonded joints were ruptured in the basic material. It is possible to recommend some of the group of four adhesives, shown in Fig. 3 left (D2, HE, PR, PW). The adhesives DB and 10 can be not recommended, because at the same strength they are multiple more expensive. The adhesive PA cannot be also recommended, because its strength is low and the joints are expensive.

For the direction 90º similar results were determined. The bonded joint strength was even lower than for the direction 45º. For bonding it is possible to recommend or not recommend adhesives mentioned in the previous paragraph.

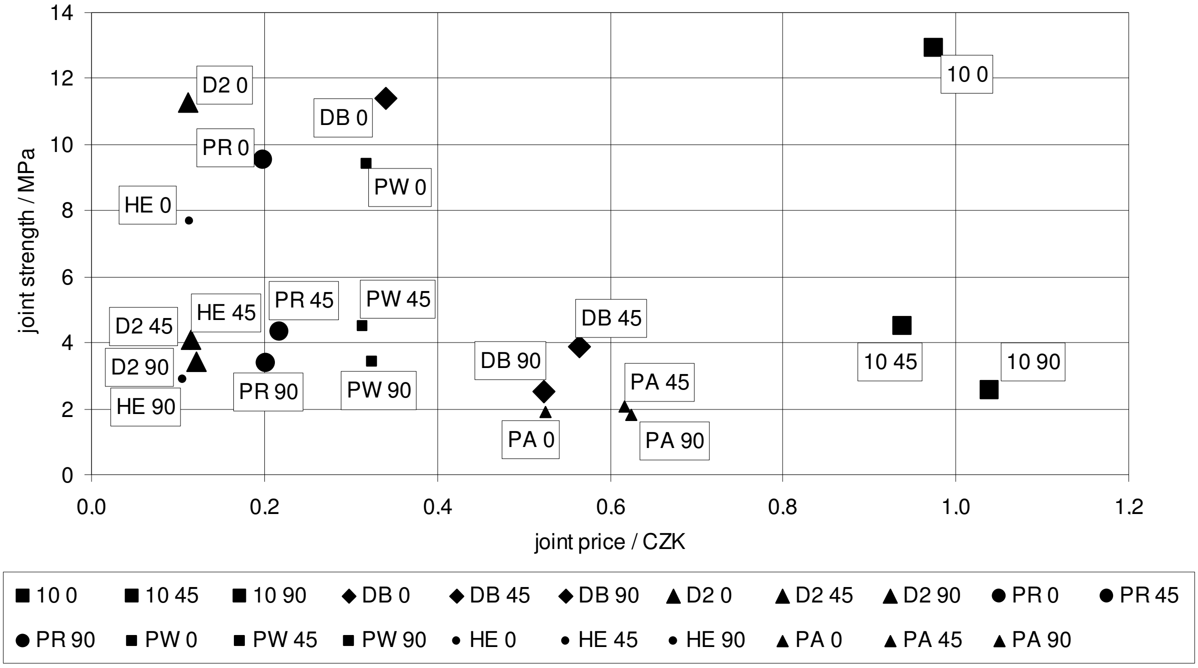

Fig. 3. **Strength and price of bonded joints at the use of different adhesives**

Conclusion

The paper presents the strength results of the laboratory tests carried out according to the modified standard CSN EN 1465 (66 8510) using the samples made from the beech three-ply plywood of 4 mm thickness (ČSN EN 636). From the plywood sheet of size 2500 x 1250 mm the samples were cut out lengthwise (0º), in the direction of 45º and crosswise (90º).

The bonded joints were made using seven different adhesives of domestic as well as foreign producers. The bonding was made exactly according to the producer recommendations. After bonding the assemblies were left in a laboratory till to the adhesive total curing. The samples were loaded using the universal tensile testing machine till to the rupture. The maximum force was noted. The highest strength in the lengthwise direction (0º) was determined at the adhesive 1001U super glue (12.9±1.5 MPa). Gradually decreasing strength was determined at the adhesives Den Braven super glue (11.4±0.8 MPa), wood glue D2 (11.3±0.7 MPa), Pritt gamafix white (9.5±0.7 MPa), Pattex Wood Standard (9.4±0.7 MPa) and Herkules (7.7±0.5 MPa). The lowest joint strength was measured at the use of the adhesive Pattex 100 % (1.9±0.4 MPa).

The part of the evaluation was the assessment of the samples rupture after the test.

From the test results it follows that from the point of view of the final strength not only the type of used adhesive but also the direction of the loading force is dominant. The joint rupture occurred either in the adhesive layer (load direction 0º) or in the basic material (load directions 45º and 90º).

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.

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