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Bonding of plywood

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Abstract

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The contribution contains results of bonded joints strength tests. The tests were carried out according to the modified standard ČSN EN 1465 (66 8510):2009. The spruce three-ply wood of 4 mm thickness was used for bonding according to ČSN EN 636 (49 2419):2013. The test samples of 100 × 25 mm size were cut out from a semi-product of 2,440 × 1,220 mm size in the direction of its longer side (angle 0°), in the oblique direction (angle 45°) and in the direction of its shorter side (crosswise – angle 90°). The bonding was carried out using eight 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 carried out.

Keywords: adhesive; spruce three-ply wood; bonded joints testing; cost of bonding

An 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 rapid development of production of synthetic adhesives, binders and cements, 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 (Brožek 2011, 2012), soldering (Brožek 2013b,c), riveting and screwing. It is necessary to consider adhesive bonding as a supplement of the above-mentioned methods, not as their substitution.

For the successful application of adhesives in practice, good knowledge of the bonding technology and of the used adhesives technological properties is 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 the bonded surfaces. 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 bonded structure etc. (Epstein 1954; Cagle et al. 1973; Loctite 1988; Pizzi, Mittal

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2003; Ebnesajjad 2008) have a substantial influence on the bonded joint final strength.

At present, bonding of plywood is still very topical. Many authors look at it from different view angles. Sellers (1989), Olivares and Sellers (1994), Chen (1995), Yang, et al. (2006), Cheng and Wang (2011), Fan et al. (2011), Garcia Esteban et al. (2011), He et al. (2012) engaged intimately in the issues of plywood production in production plants, in research and development of new types of adhesives or in plywood properties.

Nováková and Brožek (2009) and Brožek (2013a,d, 2014) engaged in pine and beech plywood bonding using adhesives. They proved that the final strength influences at most the angle of samples cutting out from a semi-product (lengthwise, angle 0°, in the oblique direction, angle 45° or crosswise, angle 90°). At the same time, they proved that the joints bonded using different adhesives show different load capacity and that the influence of surface roughness is relatively small.

MATERIAL AND METHODS

For the tests, eight types of domestic as well as foreign adhesives were purchased (Table 1).

Note: Index 0, 45 or 90 at the designation denotes the direction of the cutting out from a semi-product (lengthwise, in the oblique direction, crosswise).

Exchange rate at 28. 04. 2015: 1 EUR = 27.440 CZK, 1 USD = 25.343 CZK.

Test samples were cut out from a three-ply plywood sheet (according ČSN EN 636:2013) of size 2,440 × 1,220 mm and of 4 mm thickness in different directions – in the direction of the longer semi-product size (angle 0°), in the direction of the shorter semi-product size (angle 90°) and in the oblique direction (angle 45°). Plywood was chosen because it is an easily accessible and universally applicable material of low price.

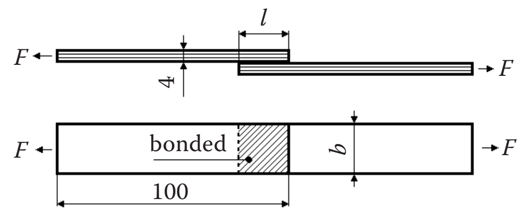

Fig. 1. Tested assembly consisting of two bonded samples (b = 20 mm, l = 12.5 mm) (Brožek 2014)
F – rupture force (N); b – overlapping width (mm); l – overlapping length (mm)

For strength testing of plywood joints the test according to the modified standard ČSN EN 1465 (66 8510):2009 was used. The bonded assembly is evident from Fig. 1.

The bonding was carried out according to the recommendations of the relevant adhesive producer. At the tested assemblies preparation the manual batching was used. From each adhesive type and from each direction of samples cutting out from a semi-product 12 bonded assemblies were prepared (at a pressure of 1.25 MPa and a temperature of 22 ± 2°C). The amount of the adhesive needed for the bonding of each run was determined.

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

Table 1. Summary of tested adhesives

No.	Abr.	Name on the wrapping	Producer/Supplier	Wrapping weight (g)	Wrapping price	Price (CZK/g)
1	AI	AIT Super Glue	AsisImport, s.r.o., Úvaly, Czech Republic	3	5	1.67
2	BK	Bastel-Kraft Kleber	Tinchant NV/SA, Berchem, Belgium	27	29	1.07
3	BW	Bison Wood Glue	Bison International, Goes, Netherlands	75	59.9	0.80
4	DB	Den Braven Wood Glue D2	Den Braven Czech and Slovak a.s., Úvalno, Czech Republic	250	43	0.17
5	PA	Pattex 100%	Henkel ČR, spol. s.r.o., Prague, Czech Republic	100	154	1.54
6	PW	Pattex Wood Waterproof	Henkel ČR, spol. s.r.o., Prague, Czech Republic	250	189	0.76
7	SS	Samson Super Glue Gel	Z-TRADE, spol. s.r.o., Broumov, Czech Republic	3	18	6.00
8	UH	UHU Power	UHU GmbH & Co. KG, Bühl, Germany	39	66	1.69

Abr. – abbreviation in the text

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measured. From these values the bonded joint surface S (mm^2) 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 of the bonded assembly (MPa) 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 of the tests carried out was to evaluate the influence of the load direction (0°, 45° and 90°) 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 (84.5%) at the samples cut out lengthwise (0°). At the samples cut out in the oblique direction (45°) the rupture occurred sometimes in the bonded joint (61.5%), sometimes in the plywood (38.5%). At the samples cut out crosswise (90°) the rupture occurred mostly (69.4%) in the plywood.

However, between the tested adhesives relatively great differences exist. At the samples cut out lengthwise (0°) using the adhesives PA and UH the rupture occurred always in the bonded surface. It is caused, first of all, by the mechanical properties of bonded joints made using these adhesives and contemporarily by the highest strength of the plywood bonded in this direction. When adhesives of mildly better properties were used, the situation was different. At the samples bonded using adhesives PW and BW the rupture in the bonded surface occurred at 94.4% or 93.1% of assemblies, at the adhesive BK at 80.6% of the bonded assemblies. Using the adhesives AI, DB and SS the rupture in the bonded surface occurred at less than 80% of tested joints, namely at 77.8%, 68.1% and 62.5% joints, respectively. In the remaining cases the rupture occurred in the plywood.

The analogous case was at samples cut out in the oblique direction of 45°. The results are influenced not only by the adhesive properties but also by the plywood reduced strength in this direction. The lowest properties were determined at the adhesive UH, when 94.4% of assemblies were ruptured in the bonded surface. At the adhesive PW the rupture occurred in 73.6% of cases. The joints using other adhesives showed the bonded joint ruptures in the range between 65.3% and 34.7% in this descending order: BW, PA, AI, BK, SS and DB.

At the samples cut out crosswise (angle 90°) the lower strength of plywood was shown in this direction. It is influenced by the fact that two plies of three-plywood are in the direction of the semi-product longer side (angle 0°) and one crosswise

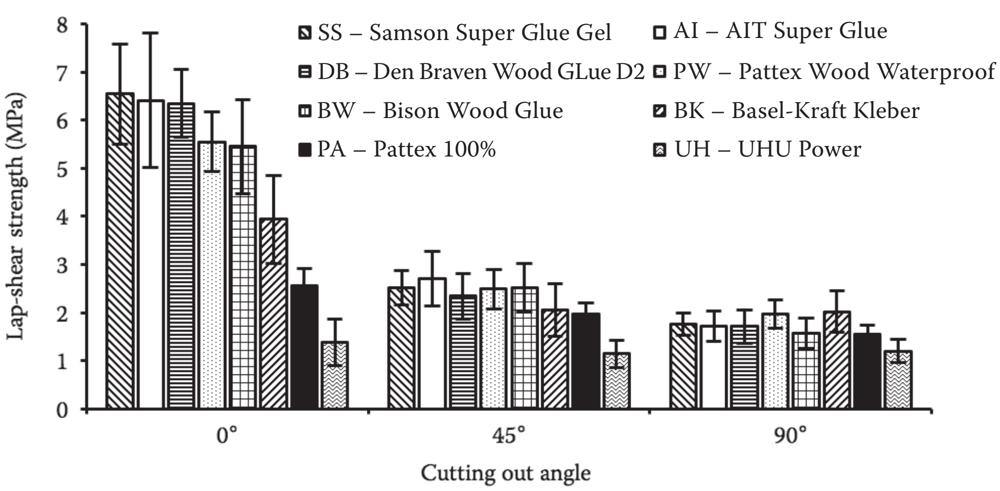

Fig. 2. Relationship between the tensile lap-shear strength and the cutting out angle; standard

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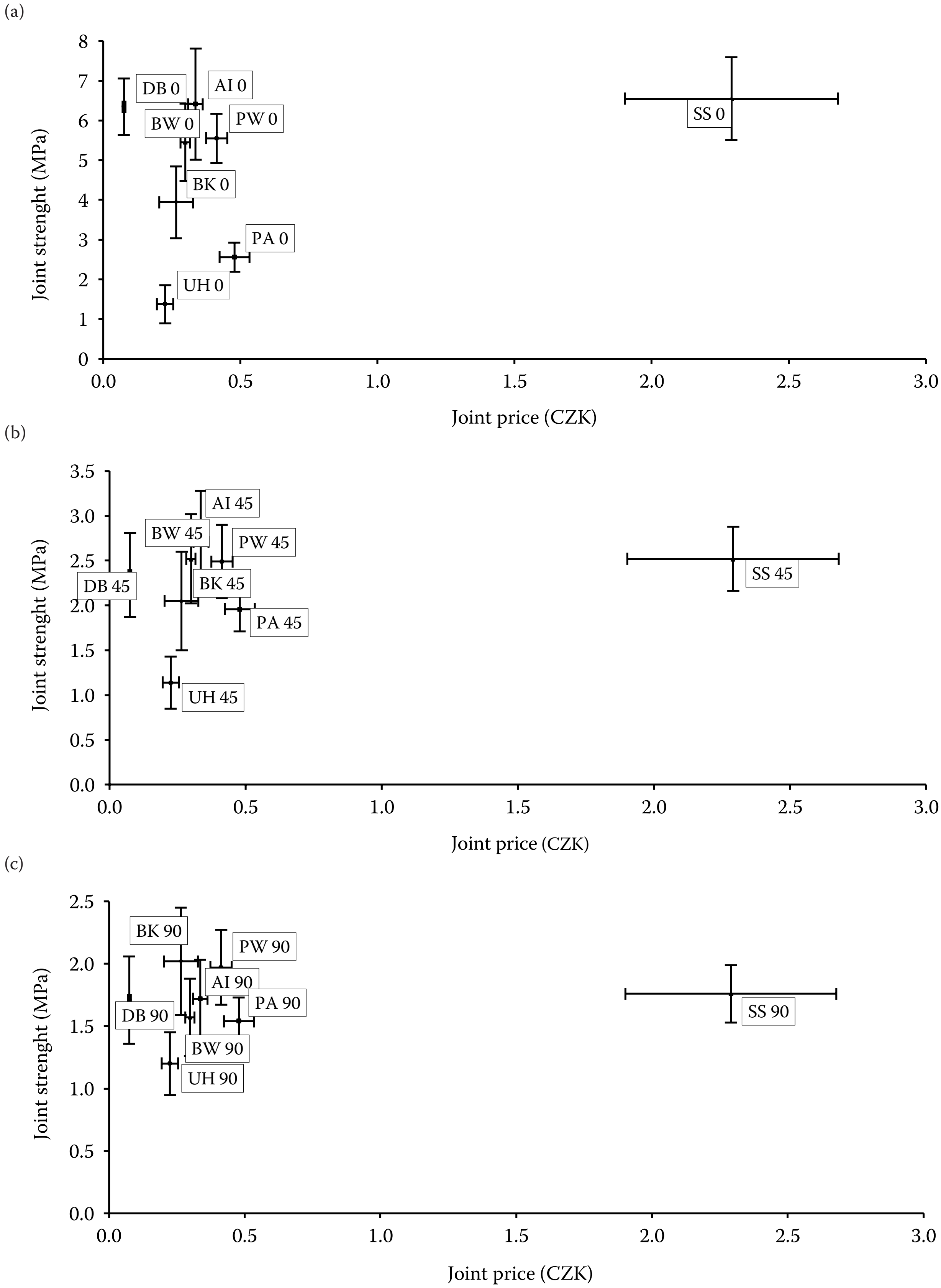

Fig. 3. Strength and price of bonded joints at the use of different adhesives (angle 0°) (a), (angle 45°) (b) and (angle 90°) (c) standard deviation is demonstrated by the line segments

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(angle 90°). The lowest properties were determined at the adhesive UH, when the rupture of the bonded joint occurred in 83.3% of cases. At joints bonded by remaining adhesives the rupture in the bonded joint occurred in less than 55% of cases. In the remaining cases the rupture occurred in the plywood. The order of adhesives was following: BW, PW, DB, PA, AI, SS (0%) and BK (0%).

At the total evaluation of the tested adhesives regardless of the samples cutting out direction from the semi-product we come to the conclusion that the most universal adhesive was the adhesive SS, where the total percentage of ruptures in the bonded joint was the lowest (35.6%). At the remaining 64.4% of bonded assemblies the rupture in the plywood occurred. The descending order of next adhesives was following: BK, DB, AI, PA, PW and BW. At the adhesive UH the rupture in the bonded joint occurred in 92.6% of cases. It means that only at 7.4% of bonded joints the rupture of the bonded material occurred.

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 0°).

From the results (Fig. 2) it is evident that the load direction with regard to the plywood production influences the strength at most. In the longitudinal direction (0°) the joint rupture occurs in the adhesive layer, because the bonded material is more strong that the adhesive. On the contrary, in next directions (45° and 90°) the plywood is less strong than the adhesive.

From Fig. 2 it is evident that for different adhesives the very different bonded joint strengths were determined. The highest strength in the lengthwise direction (0°) was determined at the adhesive Samson Super Glue Gel (SS, 6.6 MPa). Gradually decreasing strength was determined at the adhesives AIT Super Glue (AI, 6.4 MPa), Den Braven Wood Glue (DB 6.4 MPa), Pattex Wood Waterproof (PW, 5.6 MPa), Bison Wood Glue (BW, 5.5 MPa), Bastel-Kraft Kleber (BK, 3.9 MPa) and Pattex 100 % (PA, 2.6 MPa). The lowest joint strength was measured at the use of the adhesive UHU Power (UH, 1.4 MPa). In the longitudinal direction (0°) the strength values are not expressively influenced by the plywood strength. The ratio of the highest to the lowest strength is about 4.7.

In the oblique direction (45°) the order of joints strength was changed. It is caused by the fact that the bonded joint strength is influenced by the strength of the used plywood. The highest joint strength was determined at the adhesives AI (2.7 MPa), SS (2.5 MPa), BW (2.5 MPa) and PW (2.5 MPa). The next order was following: DB (2.3 MPa), BK (2.1 MPa) and PA (2.0 MPa). The lowest strength was determined at the joints bonded using the adhesive UH (1.1 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 (90°). The highest joints strength was determined at the use of the adhesives BK (2.0 MPa), PW (2.0 MPa), SS (1.8 MPa), AI (1.7 MPa) and DB (1.7 MPa), the lowest one at the use of the adhesive UH (1.2 MPa). The ratio of the highest to the lowest strength is about 1.5.

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. At measured values (Figs 2 and 3) the standard deviation is demonstrated by the line segments.

The differences between prices of the tested adhesives are very great (Table 1). The most expensive tested adhesive Samson Super Glue Gel was 35 times more expensive than the cheapest Den Braven Wood Glue 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 (0°, 45°, 90°). From the technical-economical point of view the most advantageous and thus 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.

Moreover, it is always necessary to define unequivocally requirements on the bonded joint. For some applications, the maximum strength of the joint can be demanded regardless of its price. For other applications, the adequate strength at the adequate price can be demanded. This criterion can be expressed by the ratio of the joint strength (MPa) to the joint price (CZK).

For the direction 0° (Fig. 3a) and at the criterion of the max. strength it is possible to recommend the adhesive Samson Super Glue Gel (6.6 MPa). The lower strength was determined at joints bonded using the adhesives AIT Super Glue (6.4 MPa)

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and Den Braven Wood Glue D2 (6.4 MPa). In accordance with the above-mentioned criterion of adequate strength at adequate price the adhesive DB (ratio 84.7) was found as the best and next the adhesives AI (19.1) and BW (18.2).

For the direction 45° (Fig. 3b) the considerably lower load capacity of bonded joints compared with the direction 0° was reached. Above all, it is caused by the influence of the strength of the bonded material – spruce plywood. Some of adhesives AI (2.7 MPa), SS (2.5 MPa), BW (2.5 MPa) and PW (2.5 MPa) can be recommended, too. At the use of the criterion of the ratio strength/price the maximum value of this criterion was determined at the adhesive DB (31.2) and next at the adhesives BW (8.4) and AI (8.1).

For the direction 90° (Fig. 3c) similar results were determined. The bonded joint strength was even lower than for the direction 45°. For the criterion of the maximum strength the adhesives BK (2.0 MPa), PW (2.0 MPa) and SS (1.8 MPa) were found out as the best. As it is evident, the differences in strength are minimal. At the use of the criterion of the ratio strength/price the highest value was determined at the adhesive DB (22.8) and next at the adhesives BK (7.6), UH (5.3) and BW (5.3).

CONCLUSION

The paper presents the strength results of the laboratory tests carried out according to the modified standard ČSN EN 1465 (66 8510):2009 using the samples made from the spruce three-ply plywood of 4 mm thickness according to ČSN EN 636 (49 2419):2013. From the plywood sheet of size 2,440 × 1,220 mm the samples were cut out lengthwise (0°), in the direction of 45° and crosswise (90°).

The bonded joints were made using eight 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 the adhesive total curing. The samples were loaded using the universal tensile testing machine till to the rupture. The maximum force was noted.

In the lengthwise direction (0°) the highest strength was determined using the adhesive Samson Super Glue Gel. The lower strength was determined using the adhesives AIT Super Glue, Den Braven Wood Glue D2 and Bison Wood Glue. However, at the use of the criterion of adequate strength at adequate price the situation is different. In such a case the use of the adhesive Den Braven Wood Glue D2 is the most favourable and next the use of the adhesives AIT Super Glue and Bison Wood Glue. At the test samples cut out in the directions 45° and 90° the bonded joint strength was considerably influenced by the lower strength of the plywood. As it is evident from the test results, the strength of the bonded joint does not exceed the value of 2.7 MPa at the use of all tested adhesives.

The part of the evaluation was the assessment of the assemblies 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 or in the basic material.

In the contribution, the methodology of technical-economical evaluation of tested adhesives and of bonded joints was published. 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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