WOOD WEAR RESISTANCE TO BONDED ABRASIVE PARTICLES

M. Brožek

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

Abstract
In this contribution the results of the wear resistance study of twelve types of wood commonly growing in the Czech Republic are published. The laboratory tests were carried out using the pin-on-disk machine with abrasive cloth according to the modified standard ČSN 01 5084. The abrasive track length and the abrasive clothes of three different grits were used. The wear intensity was assessed by the volume, weight and length losses of tested samples. The technical-economical evaluation was the part of the carried out tests. The samples from spruce and pine were the cheapest. The samples from locust and walnut were the most expensive. From the point of view of wear the most favourable results were determined at the samples from oak. Regardless of the criterion of assessment the wood of oak was keenly priced and it had the smallest wear without regard to the used abrasive cloth grit.

Key words: DMA wood, abrasive wear, bonded abrasive particles, wear resistance, laboratory tests.

INTRODUCTION

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 has been utilized to construction of buildings and fortifications, building of means of transport (ships and wagons) and tools.

In contrast to other used materials (metals, plastics, aggregate, limestone, glass, ceramics) wood has one exceptional property – it is a case of 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; KETTUNEN, 2006; PESCHEL, 2002; PLUHAŘ ET AL., 1989). 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 let us specify at least elasticity, strength (tensile, pressure, bending, shear, torsion), hardness, toughness. Technological properties of wood are also exceptional, e.g. machinability, bending ability, loading capacity of metallic binders, wear resistance or various defects. For some applications, e.g. floors and staircases, the wear resistance is very important (KRÁL AND HRÁZSKÝ, 2008; LIU ET AL, 2012; OHTANI ET AL, 2001; OHTANI ET AL, 2002; OHTANI ET AL, 2003; ČSN 01 5050, 1969; ČSN 49 0134, 1984; ČSN EN 13696, 2009; ČSN 91 0276, 1989).

Even today wood is considered for a very good building material. The greatest consumer of wood is therefore building industry, followed by cellulosic-paper industry (FAHERTY AND WILLIAMSON, 1995; SLAVID, 2009; TSOUMIS, 1991; ZAHRADNÍČEK AND HORÁK, 2007). Production of furniture, musical instruments, works of art, sports equipment or of toys for children represent an interesting utilization of wood. A part of wood is consumed in form of firewood.

The aim of this study is to determine woods wear resistance of selected woods.

MATERIALS AND METHODS

In the contribution the results of abrasive wear resistance study of twelve types of wood (ash, birch, cherry, larch, lime, locust, maple, oak, pine, poplar, spruce and walnut) are published. The laboratory tests were carried out using the pin-on-disk machine with abrasive cloth, when the abrasive clothes of three different grits were used. The wear intensity of all test samples was assessed by volume, weight and length losses at different conditions.

The part of carried out tests was the technical-economical evaluation, too. The prices of test samples from wood were calculated from the actual price of semi-finished products (board, balk, trunk) used for their production. The used prices are the average prices of wood in the Czech Republic at January 2014.

For the materials wear resistance determination against single wear types (ČSN 01 5050, 1969) in principle field tests, pilot tests and laboratory tests are used. Each of mentioned tests is of advantages, but also of disadvantages. Therefore each of test types is most suitable for other field of application. The wear resistance test type is always necessary to be chosen with regard to the in wear process dominant conditions and to the demanded test results (BROŽEK, 2007).

The wear intensity can be expressed by the directly measured values or by the relative values. The directly measured value can be abrasion specified in length (cm), weight (g) or volume (cm^3). The other possible way is the expression by the dimensionless quantity, when wear intensity of the tested sample is compared to the wear intensity of the standard (VOCEL, 1993; VOCEL AND DUFEK, 1976).

In literature a sufficient number of wear resistance testers for various types of wear is mentioned (BLAU, 1992; FRICTION AND WEAR TESTING, 1987; LEVER AND RHYS, 1968; VOCEL, 1993). Testing equipment for abrasive wear resistance determination is usually classified according to the contact mode of the sample with free or bonded abrasives. In practice the testing machines with abrasives bonded to cloth (Fig. 1) are used most often. They are simple and reliable, with small variance in results. Their disadvantage is the variable quality of abrasive cloth. In Czech Republic this testing method is standardised according to standard ČSN 01 5084 (similar foreign standards: STN 01 5084, ASTM G 132).

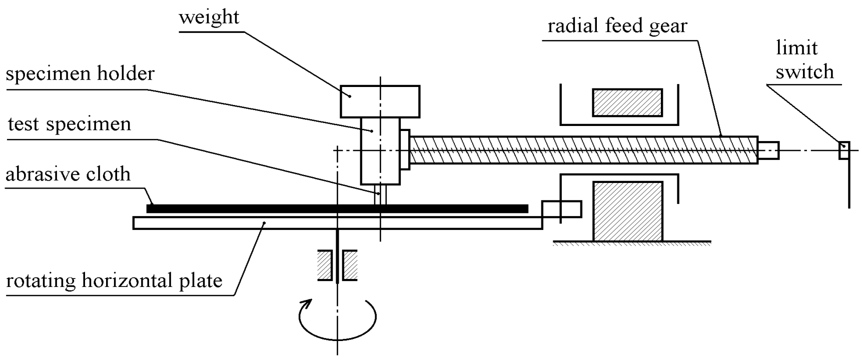

Fig. 1. – Scheme of the abrasion testing machine (pin-on-disk)

The principle of an abrasive wear test using the pin-on-disk machine with abrasive cloth (ČSN 01 5084; Fig. 1) is to wear the specimen under pre-determined conditions. Using the apparatus with abrasive cloth the samples were of 10 mm diameter and 70 mm length. The test sample is pressed against an abrasive surface using the prescribed normal force. The wear path is a spiral on the disk, caused by a disk rotation and a radial feed of a sample, so the sample progressively moves over the unused abrasive along the prescribed track length.

As abrasive cloth the corundum twill type A 99 – G, S 25, trade mark Globus, grit 120, was used. In addition tests using grits 60 and 240 were carried out, too. It corresponds to the average abrasive grain sizes of 44.5 μm (grit 240), 115.5 μm (grit 120) and 275 μm (grit 60) (BROŽEK ET AL., 2010). During the test the test sample was pressed to the abrasive cloth by the pressure of 0.1 MPa. The wear path total length was 250 m.

The above mentioned pin-on-disk machine with abrasive cloth (bonded abrasive) is primarily destined for the determination of abrasive wear resistance of metallic materials (BROŽEK, 2012; BROŽEK AND NOVÁKOVÁ, 2008; CIESLAR ET AL., 2013). By the carried out tests it was proved that this machine is suitable and applicable for wear resistance tests of plastics (BROŽEK, 2015) and wood, too.

In practice also machines of other design are used, e.g. machine with rubber cylinder. In this case the test sample is worn out by free abrasive, which is poured between the sample surface and the slowly rotating cylinder, which touches the sample surface. The rubber cylinder pushes the free abrasive grains against the tested sample surface. The used grains fall in a container (BUDINSKI, 1997).

The summary of the used materials, their density and price of test samples are stated in Tab. 1. Moisture of tested woods ranged from 8.3 to 9.1 %.

Tab. 1. – Summary of tested materials

Tested material	Density g·cm^{-3}	Price of test sample CZK	Price of test sample EUR	Price of test sample USD
ash	0.688	0.403	0.015	0.017
birch	0.695	0.516	0.019	0.021
cherry	0.804	0.901	0.033	0.037
larch	0.888	0.379	0.014	0.016
lime	0.542	0.282	0.010	0.012
locust	0.751	1.378	0.051	0.057
maple	0.726	0.426	0.016	0.018
oak	0.798	0.581	0.021	0.024
pine	0.584	0.228	0.008	0.009
poplar	0.553	0.402	0.015	0.017
spruce	0.427	0.222	0.008	0.009
walnut	0.638	1.199	0.044	0.049

For information: 1 EUR = 27.0650 CZK; 1 USD = 24.2670 (24 March 2016)

Before the abrasive wear test the density (ρ) of all tested materials was determined. Using a dial balance the sample weight (g) before (m_1) and after (m_2) the test was determined with the accuracy of 0.0001 g.
At the preparatory tests it was determined that at grinding of wood using abrasive cloth no abrasiveness reducing occurs, as it is known at metallic materials. Therefore at metallic materials it is by the standard prescribed to use for the next test new cloth. At tested woods the dependence between weight loss and track length was always linear with the high value of the coefficient of determination R^2 (from 0.998 to 1.000). Therefore the test procedure prescribed by the standard (ČSN 50 0184, 1974) could be adapted.
After the abrasive path of 50 m completion the abrasive cloth was carefully cleaned from the tested material worn out particles and again used. The test was repeated five times. By this way the weight losses of all tested samples after the wear path of 50 m, 100 m, 150 m, 200 m and 250 m were determined. For the next material test the new abrasive cloth was used.
The weight loss Δm (g) is calculated using the equation:

$$\Delta m = m_1 - m_2 \quad (1)$$

The volume loss ΔV (cm^3) is calculated from the weight loss Δm (g) and the density ρ (g·cm^{-3}) (Tab. 1) from the equation:

$$\Delta V = \frac{\Delta m}{\rho} \quad (2)$$

The length loss Δl (cm) is calculated from the volume loss ΔV (cm^3) and from the worn out sample front surface from the equation:

$$\Delta l = \frac{4.\Delta V}{\pi.d^2} \quad (3)$$

RESULTS AND DISCUSSION

In next Figures the woods are arranged according to the decreasing weight loss using the abrasive cloth of grit 240 (the average abrasive grain size 44.5 µm).
From the test results shown in Fig. 2 (weight loss) and in Fig. 3 (volume loss/length loss) it follows that different woods have different abrasive wear resistance. The order of tested woods arranged according to the decreasing weight/volume loss is identical. It is logical owing to the same worn out front surface diameter of all tested samples.
At the test using the pin-on-disk machine the highest wear was determined at the wood lime (Fig. 2). The wear intensity of next woods decreased in order birch, locust, larch, walnut, poplar, pine, ash, spruce, cherry and maple. The minimum wear was determined at the wood oak.
Concurrently the wood of oak showed 51 % wear of the wood of lime. At the wear using the abrasive cloth of grit 120 (115.5 µm) the woods placing changed. The highest wear was determined at lime. The next placing in descending order was larch, pine, locust, birch, walnut, spruce, poplar, maple, ash, cherry and oak. Concurrently the wood of oak showed 46 % wear of the wood of lime. At the wear using the abrasive cloth of grit 60 (275 µm) the woods wear placing in ascending order was larch, locust, lime, walnut, poplar, ash, maple, pine, birch, cherry, spruce and oak. Concurrently the wood of oak showed 42 % wear of

the wood of larch. So from the results it follows that at the increasing size of abrasive particles the ratio between the wear rate of the least and most wear resistant woods decreases. It means that the properties of the concrete wood influence less its wear. From the carried out tests it also follows that the average wear of wood samples regardless of their type is the greatest using the abrasive cloth of grit 120 (1.165 ± 0.260 g), smaller using the abrasive cloth of grit 60 (1.033 ± 0.262 g) and the smallest using the abrasive cloth of grit 240 (0.698 ± 0.155 g). From this fact it follows that the wear of wood depends significantly on the abrasive particles size. The greatest wear is caused by particles of medium size, small and big particles cause a smaller wear.

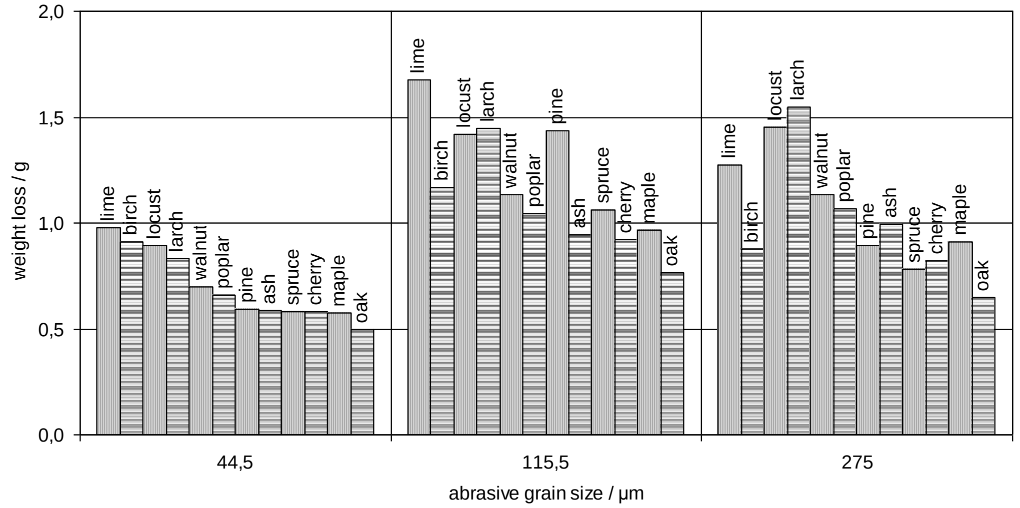

Fig. 2. – Weight loss

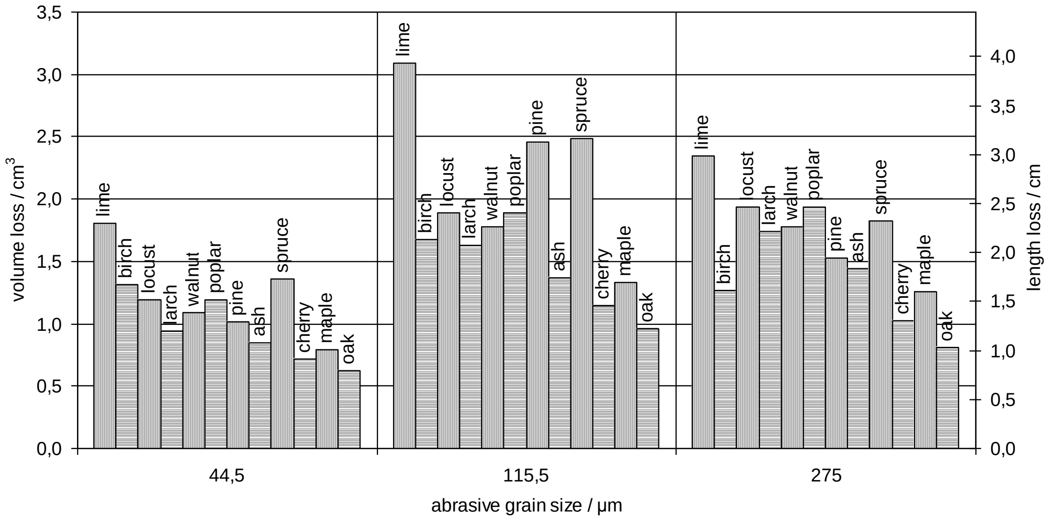

Fig. 3. – Volume/length loss

In comparison with Fig. 2 to Fig. 3 it is evident that the order of tested woods wear intensity expressed by volume/length loss does not correspond to the order expressed by weight loss. It is caused by the considerably different density of the tested woods (Tab. 1). The greatest volume/length wear using the abrasive cloth of grit 240 was determined at lime and it decreased in order of woods spruce, birch, locust, poplar, walnut, pine, larch, ash, maple, cherry and oak. Using the abrasive cloth of grit 60 the order of woods was lime, poplar, locust, spruce, walnut, larch, pine, ash, birch, maple, cherry and oak. From the point of view of volume/length loss the wood of lime was the least wear resistant, the wood of oak the most wear resistant. At the use of all abrasive cloth grits the volume/length loss of the wood oak ranged from 31 % to 34 % of the wood lime.

The graphical illustration of the technical-economical evaluation of the carried out tests is evident from Fig. 4 (according to weight loss) and Fig. 5 (according to volume/length loss). Both of diagrams represent the results of the tests carried out using the abrasive cloth of grit 120 (average abrasive grain size 115.5 µm).

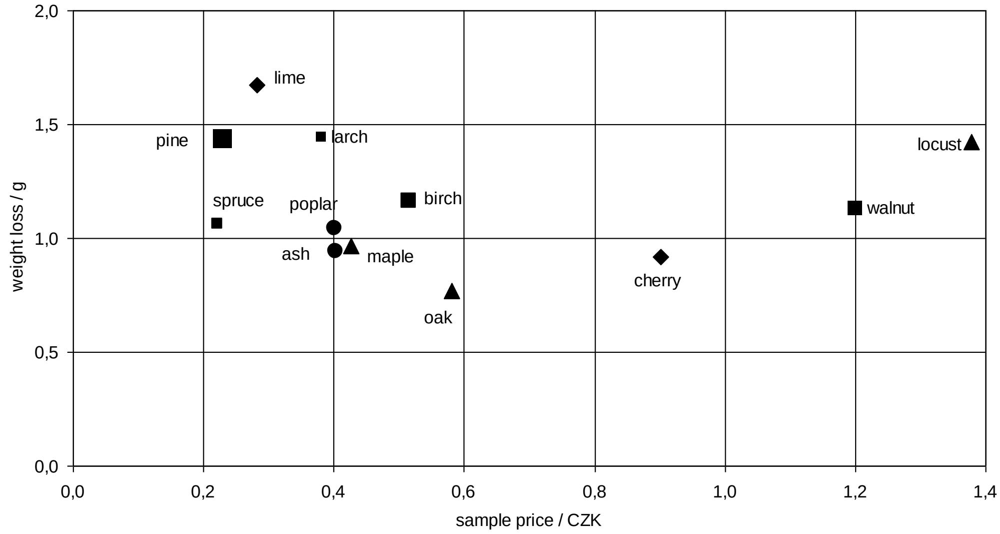

Fig. 4 – Relationship between weight loss and sample price

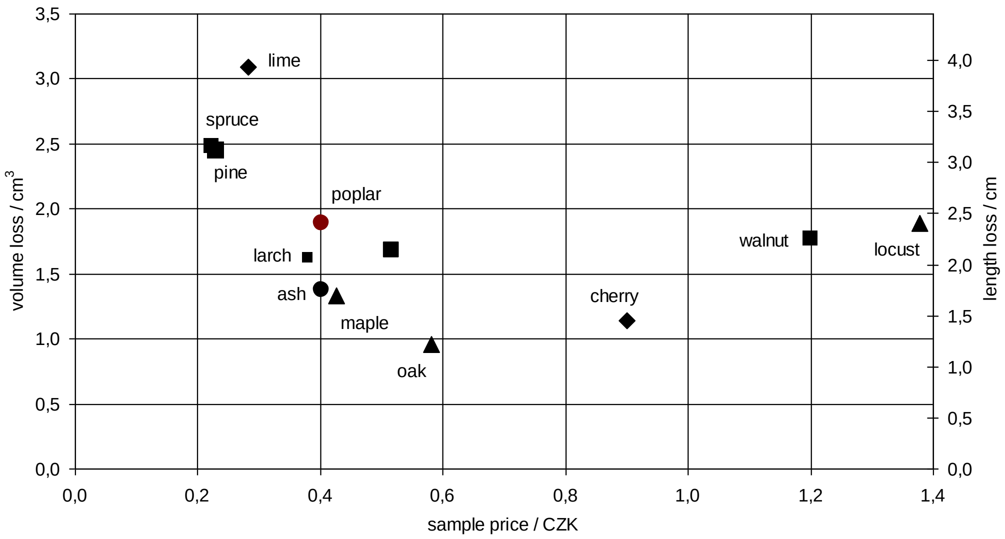

Fig. 5 – Relationship between volume/length loss and sample price

In Figs 4 (weight loss) and 5 (volume/length loss) the results of for practice most suitable woods from the technical-economical point of view are located left at the bottom. It is a case of keenly priced materials of relatively small wear. On the contrary the results of woods located right on the top are not suitable for use in conditions of abrasive wear. It is a case of material low wear resistance and high price.

As it is evident from Fig. 4 the greatest weight loss is shown by the woods of lime, pine, larch and locust. The first mentioned woods are cheap. The wood from locust is multiple expensive (Tab. 1). On the contrary the smallest weight loss is shown by the wood of oak, cherry, maple and ash. The woods of ash and maple are at the same time keenly priced.

From the point of view of wear expressed by volume/length loss (Fig. 5) the greatest wear was determined at the woods of lime, spruce and pine, the smallest wear was determined at the woods of oak, cherry and maple. The medium wear was determined at the woods of walnut and locust, but which are the most expensive. The price of the samples ranged from 0.222 to 1.378 CZK (from 0.008 to 0.051 EUR or from 0.009 to 0.057 USD) per unit.

On the basis of the carried out tests the wood of oak proved to be the abrasive wear most resistant. It has the smallest wear regardless in the way of the wear resistance definition (weight loss, volume/length loss) and it is relatively keenly priced.

From the results summarization of the carried out tests it follows that at the different materials wear resistance evaluation it is necessary to give the parameter of loss. As it is showed in above mentioned figures, the results expressed by volume or length loss (Fig. 3) are at the same size of test samples identical, while results expressed by weight loss (Fig. 2) differ.

CONCLUSIONS

The contribution contains the laboratory tests results of abrasive wear resistance of selected wood using the pin-on-disk machine with abrasive cloth. In total twelve types of wood commonly growing in the Czech Republic (ash, birch, cherry, larch, lime, locust, maple, oak, pine, poplar, spruce and walnut) were tested. The aim of the carried out tests was to assess the possibility of their use for products, which are intensively worn out, e.g. terraces or staircases.

All samples were of cylindrical shape of 10 mm diameter and 70 mm length. For the test samples wear three abrasive clothes of different grit, namely 240 (average abrasive grain size 44.5 µm), 120 (average abrasive grain size 115.5 µm) and 60 (average abrasive grain size 275 µm) were used. The test of all materials was carried out according to the modified standard ČSN 01 5084 except that using the same abrasive cloth the sample was worn out five times, which means using the path 50 m 100 m, 150 m, 200 m and 250 m. After each test of one material the abrasive cloth was carefully cleaned from the material rests and used again. For the next material the new abrasive cloth was always used.

The wear intensity was evaluated by weight loss, volume loss and length loss at all tested samples. From the evaluation of the carried out tests it follows that the greatest difference between the most and the least wear resistant woods (oak/lime) was determined at the use of the abrasive cloth of grit 240 having the smallest abrasive particles. The difference is put by the ratio of 0.51. With the increasing size of abrasive particles this ratio decreases. Using the abrasive cloth of grit 120 it is 0.46 and of grit 60 having the greatest abrasive particles it is 0.42 (oak/larch). It was also found that the greatest wear regardless to the sort of wood are caused by the particles of the medium size (grit 120, weight loss 1.165 ± 0.260 g), the minor wear by the great particles (grit 60, weight loss 1.033 ± 0.262 g) and the smallest wear by the small particles (grit 240, weight loss 0.698 ± 0.155 g).

The technical-economical evaluation was the part of the carried out tests. At the same time it was proved that on the Czech market the price of wood is very different. The samples of spruce and pine were the cheapest; the samples of locust and walnut were the most expensive. From the point of view of wear resistance the most favourable results were determined at the wood of oak. Oak was relatively keenly priced and regardless of the evaluation criterion (weight loss, volume loss, length loss) and of the used abrasive cloth grit (240, 120 and 60) it had the smallest wear.

From the results of carried out tests it follows that for applications, where wood is intensively abrasively worn out, from domestic woods it is possible to recommend only oak. The other tested woods are no so wear resistant and as the case may be more expensive.

REFERENCES

1. BLAU, P. J.: ASM Handbook. Volume 18 – Friction, Lubrication, and Wear Technology (online). ASM International. 1992. available at: http://app.knovel.com/hotlink/toc/id:kpASMHVFL2/asm-handbook-volume-18. Accessed 10 November 2013.
2. BROŽEK, M.: Wear resistance of multi-layer overlays. In: 11th International Scientific Conference Engineering for Rural Development, 24-25 May 2012, Jelgava, Latvia University of Agriculture, pp. 210-215.
3. BROŽEK, M.: Technicko-ekonomické hodnoceni aplikace návarů u plužních čepelí (Technical-economical evaluation of the overlays application on plough shares). Acta Univ. Agric. et Silvic. Mendel. Brun., 55, 2007: 129-136. (In Czech).
4. BROŽEK, M.: Selected plastics wear resistance to bonded abrasive particles compared to some ferrous materials. Acta Univ. Agric. et Silvic. Mendel. Brun., 63, 2015: 387-393.
5. BROŽEK, M., NOVÁKOVÁ, A.: Evaluation of sintered carbides wear resistance. In: 7th International Scientific Conference Engineering for Rural Development, 29-30 May 2008. Jelgava, Latvia University of Agriculture, pp. 209-213.
6. BROŽEK, M., NOVÁKOVÁ, A., MIKUŠ, R.: Study of wear resistance of hard facings using welding powders on the NiCrBSi basis. In: 4th International Conference Trends in Agri-

cultural Engineering 2010. 7-10 September 2010. Prague, Czech University of Life Sciences Prague, pp. 115-118.
7. BUDINSKI, K. G.: Resistance to particle abrasion of selected plastics. Wear, 203-204, 1997: pp. 302-309.
8. CIESLAR, J. – BROŽEK, M. – BEDNÁŘ, B.: An experimental assessment of special metal castings in reducing abrasive wear. Manufacturing Technology, 13, 2013: 423-428.
9. FAHERTY, K. F., WILLIAMSON, T. G.: Wood engineering and construction handbook. 2nd ed., New York, Osborne-McGraw-Hill 1995.
10. Friction and Wear Testing. American Society for Testing and Materials. West Conshohocken, PA, American Society for Testing and Materials 1987.
11. KAFKA, E.: Dřevařská příručka (Woodworking guide). Praha, Nakladatelství technické literatury. 1989. (In Czech).
12. KETTUNEN, P. O.: Wood: Structure and properties. Uetikon-Zuerich, Enfield, Trans. Tech. Publication 2006.
13. KRÁL, P., HRÁZSKÝ, J.: A contribution to the resistance of combined plywood materials to abrasion. Journal of Forest Science, 54, 2008: 31-39.
14. LEVER, A. E., RHYS, J. A.: The properties and testing of plastic materials. 3rd ed., Bristol, Wright Temple Press Books. 1968.
15. LIU, Z. D., WANG, W. B., CAI, L., GUO, D. J., DAI, Z. D.: Friction and wear properties of commercial solid wood floorings. Mocaxue Xuebao (Tribology), 32, 2012: 557-562.
16. OHTANI, T., YAKOU, T., KITAYAMA, S.: Two-body and three-body abrasive wear properties of Katsura wood. J. Wood Sci., 47, 2001: 87-93.
17. OHTANI, T., YAKOU, T., KITAYAMA, S.: Effect of annual rings on abrasive wear property of wood. J. Wood Sci., 48, 2002: 264-269.
18. OHTANI, T., KAMASAKI, K., TANAKA, C.: On abrasive wear property during three-body abrasion of wood. Wear, 255, 2003: 60-66.
19. PESCHEL, P.: Dřevařská příručka. Tabulky. Technické údaje (Woodworking guide. Tables. Technical data). Praha, Sobotáles 2002. (In Czech).
20. PLUHAŘ, J. ET AL.: Nauka o materiálech (Material Science). Praha, SNTL 1989.
21. SLAVID, R.: Wood architecture. Paperback ed. London, Laurence King 2009.
22. TSOUMIS, G.: Science and technology of wood: Structure, properties, utilization. New York, Chapman & Hall 1991.
23. VOCEL, M.: Experimentální metody hodnocení tření a opotřebení (Experimental Methods of Friction and Wear Evaluation). Kovové materiály, 21, 1993. (In Czech).
24. VOCEL, M. – DUFEK, V. ET AL.: Tření a opotřebení strojních součástí (Friction and Wear of Machine Parts). Praha, SNTL 1976.
25. ZAHRADNÍČEK, V., HORÁK, P.: Moderní dřevostavby (Modern wooden houses). Brno, ERA 2007.
26. ČSN 01 5050. Opotřebení materiálu. Názvosloví. (Wear of materials. Terminology). 1969. (In Czech).
27. ČSN 01 5084. Stanovení odolnosti kovových materiálů proti abrazívnímu opotřebení na brusném plátně (Determination of metal material resistance against wear by abrasive cloth). 1974. (In Czech).
28. ČSN 49 0134. Drevo. Metóda zisťovania odolnosti proti oderu (Wood. Determination of abrasion resistance). 1984. (In Slovak).
29. ČSN EN 13696. Wood flooring - Test methods to determine elasticity and resistance to wear and impact resistance. 2009.
30. ČSN 91 0276. Nábytek. Metoda zjišťování odolnosti povrchu proti otěru (Furniture. Method of determining the surface resistance to abrasion). 1989. (In Czech).

Corresponding author:
prof. Ing. Milan Brožek, CSc., Department of Material Science and Manufacturing Technology, Faculty of Engineering, Czech University of Life Sciences Prague, Kamýcká 129, Praha 6, Prague, 16521, Czech Republic, phone: +420 22438 3265, e-mail: brozek@tf.czu.cz