SELECTED PLASTICS WEAR RESISTANCE

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Abstract. Plastics are macromolecular materials without which we cannot imagine any branch of human activity. Plastics have unique properties, often very different from metals. At the choice of concrete plastic for the concrete application it is necessary to evaluate its mechanical, physical, chemical and technological properties. In recent years producers offer also plastics for production of parts exposed to different types of wear. In the contribution the results of wear resistance studying of 10 types of plastics of one producer are published and compared with the test results of four different Fe alloys. 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 was assessed by the volume, weight and length losses of the tested samples. The technical-economical evaluation was a part of the carried out tests. It was univocally proved that at intensive abrasive wear using the abrasive cloth the best results are shown by the High-Speed Steel HSS Poldi Radeco (19 810 according to CSN 41 9810), although its price is relatively high. Other tested Fe alloys, namely grey iron according to CSN 42 2415, structural steel 11 373 according to CSN 41 1373 and wear resistant cast steel VPH 6 showed also very favourable properties at the material low price. In comparison with Fe alloys the wear of all plastics was considerably higher and the plastics were considerably more expensive.

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

Introduction

Plastics are macromolecular materials without which we cannot imagine any branch of human activity. They are classified according to different criteria. Evidently, most often plastics classification is according to the heat effect (thermoplastics, thermosetting). The next classification is according to their chemical composition (CSN EN ISO 1043-1) [1]. According to additives we distinguish plastics with filling and without filling. According to the expected use in practice we distinguish standard plastics, structural plastics and high-tech plastics [2- 4].

As citizens we meet often plastics in the form of packing materials in the widest meaning. But plastics are also a modern structural material, of which not only commonly known products are made, as toys for children, window frames, garden furniture, parts in interior of passenger cars, mobile phones housing or housings of personal computers.

History of plastics production is relatively new. The first plastic (parkesin) was made in the first half of the 19th Century. The first fully synthetic plastic was made about 100 years ago. The dynamic production increase and usage of plastics had come in the half of the last century. In some applications plastics replaced gradually until then used materials, namely wood, glass, steel or nonferrous metals. Since then the plastics production develops and increases very dynamically. From the available statistical data it follows that contemporary the year consumption of plastics is in the whole world almost 40 kg per person, in Europe almost double.

Plastics have unique properties, mostly very different from the properties of metals. At the choice of definite plastic for definite application it is necessary to appraise its mechanical, physical, chemical and technological properties. In last years producers offer also plastics for parts exposed to different types of wear [5-7]. Parts, which were formerly made from metals, today are commonly produced from plastics. As examples it is possible to give various guides, sliding bearings, wheels of wheel conveyers, sludge pipes (also containing sand), working parts of machines for soil cultivation or linings of conveying troughs for loose materials. Contemporary plastics are processed using many different technologies: moulding, calendring (sheeting), injection moulding, blow moulding, thermoforming, and cutting or welding, too. Products from plastics are finished by various surface finishing [8].

In the contribution the results of abrasive wear resistance study of 10 types of plastics are published. The results are compared with the test results of 4 different Fe alloys. The laboratory tests were carried out using the pin-on-disk machine with abrasive cloth, when the abrasive clothes of 3 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 the carried out tests was the technical-economical evaluation, too. The prices of plastics were taken over from invoices.

Materials and methods

For the material wear resistance determination against single wear types (ČSN 01 5050) [9] in principle field tests, pilot tests and laboratory tests are used. Each of the mentioned tests is of advantages, but also of disadvantages. Therefore, each of the 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 wear process dominant conditions and to the demanded test results.

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 [10].

In literature a sufficient number of wear resistance testers for various types of wear is mentioned [11-13]. 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 the Czech Republic this testing method is standardised according to ČSN 01 5084 [14].

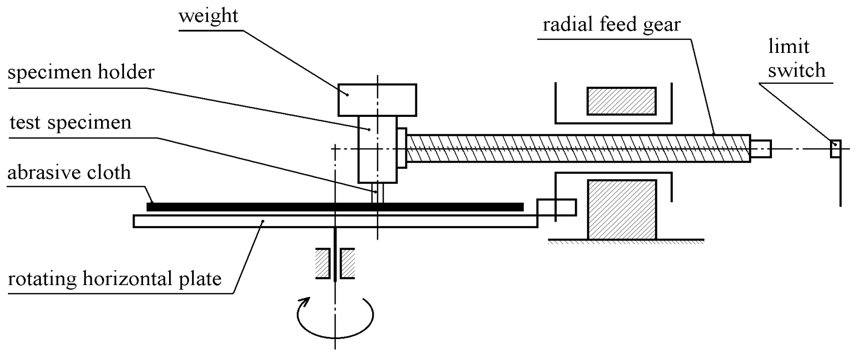

Fig. 1. **Scheme of the abrasion testing machine (pin-on-disk)**

The principle of an abrasive wear test using the pin-on-disk machine with abrasive cloth (CSN 01 5084; Fig. 1) is to wear the specimen under pre-determined conditions. Using the apparatus with abrasive cloth the specimens were of 10 mm diameter and 70 mm length. The test specimen is pressed against an abrasive surface using the prescribed normal force. The wear path is a spiral on the disk, caused by the disk rotation and a radial feed of a specimen, so the specimen progressively moves over 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 the grits 60 and 240 were carried out, too. It corresponds to the average abrasive grain sizes of 44.5 (grit 240), 115.5 (grit 120) and 275 µm (grit 60). 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 the abrasive wear resistance of metallic materials [15-20]. By the carried out tests it was proved that this machine is suitable and applicable for wear resistance tests of plastics, too.

In practice, also machines of other design are used, e.g., a machine with a 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 [6].

The summary of the used materials (plastics and metals) is in Tab. 1. 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. After the abrasive path of 50 m completion the abrasive cloth was carefully cleaned from the tested material worn out particles and used again. 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 a new abrasive cloth was used.

Table 1

Summary of tested materials

Tested material	Marking	Density, g·cm^{-3}	Price of sample material, CZK
Polytetrafluorethylene	PTFE	2.16	33.03
Polyvinyl Chloride	PVC	1.38	9.32
Polyoxymethylene (Polyacetat) Copolymer	POM-C	1.39	10.16
Polycarbonate	PC	1.20	25.75
Polyethylene Terephthalate Polyester	PETP	1.40	10.16
Polyetheretherketone	PEEK	1.32	94.86
Polyamide 6.6	PA66	1.14	11.01
Polypropylene	PP	0.91	6.78
Polyamide 6 Extruded	PA6E	1.14	7.62
Polyethylene Ultra-high-molecular-weight	PE-UHMW	0.93	13.55
Grey Iron according to CSN 42 2415	GI	7.25	1.43
Structural steel 11 373 according to CSN 41 1373	SS	7.68	1.30
Cast steel VPH 6 wear resistant	CS	7.65	2.87
High-speed steel Poldi Radeco 19 810 according to CSN 41 9810	HSS	8.25	56.00

Notes:

- Plastics are marked by abbreviations according to CSN EN ISO 1043-1 (64 0002) [20].
- The samples from all plastics and steels were cut off from bars of 10 mm diameter, the samples from grey iron and cast iron from castings of a simple shape.
- At 14. 02. 2014 the exchange rate was 1 EURO = 25.435 CZK

Table 2

Chemical composition of tested Fe alloys (weight %)

Marking of tested material	Tested material	C	Si	Mn	Cr	B	W	V	Mo
GI	Grey iron ČSN 42 2415	3.93	3.76	0.38	x	x	x	x	x
SS	Structural steel ČSN 41 1373	0.17	0.19	0.47	0.04	x	x	0.00	0.01
CS	Cast steel VPH 6	0.51	0.40	1.21	0.95	0.02	x	x	x
HSS	High-speed steel ČSN 41 9810	1.25	0.28	0.32	4.41	x	10.72	4.01	0.46

The weight loss Δm (g) is calculated using the equation:

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

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:

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

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

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

Tests results and their discussion

From the test results shown in Fig. 2 (weight loss) and in Fig. 3 (volume loss/length loss) it follows that different plastics have different abrasive wear resistance. The order of the tested plastics 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.

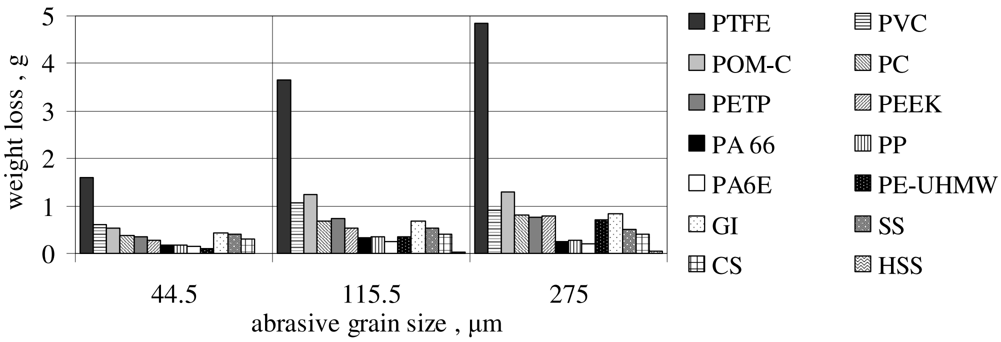

Fig. 2. **Weight loss**

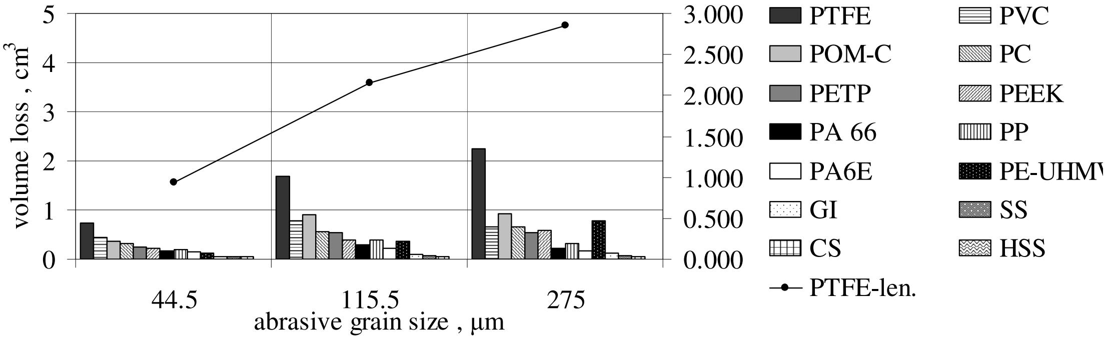

Fig. 3. **Volume/length loss**

At the arrangement of the samples according to the weight loss the samples from grey iron 42 2415, from steel 11 373 and from cast steel VPH 6 show the higher loss. It is caused by their considerably higher density compared to the density of the tested plastics. At the test using the pin-on-disk machine the highest wear was determined at the plastic PTFE. The wear intensity of the next plastics decreased in order PVC, POM, PC, PET, PEEK, PA66, PP and PA6E. The minimum wear was determined at the plastic PE-UHMW. At Fe alloys the highest wear was determined at the steel 11 373 (ČSN 41 1373) and at the cast iron VPH 6. The minimum wear of all tested materials was determined at the high-speed steel HSS Poldi Radeco 19 810 (ČSN 41 9810) regardless of the measured quantity (volume, weight, length).

It was proved that with the increasing abrasive grain size the wear intensity increases at all tested materials. But at different materials the increase of wear intensity depending on the abrasive grain size is different. It is possible to state that from this point of view between the tested plastics relatively substantial differences exist. While at the plastic PTFE with the increasing abrasive grain size the wear increases very considerably, at the plastics of types PA 66, PP and PA6E the wear increases only little. The trend of the wear increase with the increasing abrasive grain size can be seen at the tested metals, too.

After the evaluation of all carried out tests it was proved that the abrasiveness of the abrasive cloth mildly decreases in the course of the repeated test. This fact can be expressed very precisely by the conic, when the interlayed curve approximates almost to the line. The data for the material PTFE are shown in Fig. 4.

The graphical illustration of the technical-economical evaluation of the carried out tests is evident from Fig. 5 (according to weight loss) and Fig. 6 (according to volume/length loss).

In Figures 5 (weight loss) and 6 (volume/length loss) the results of for practice most suitable materials 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 the materials located right on the top are not suitable for use in conditions of abrasive wear. It is a case of material low wear and high price.

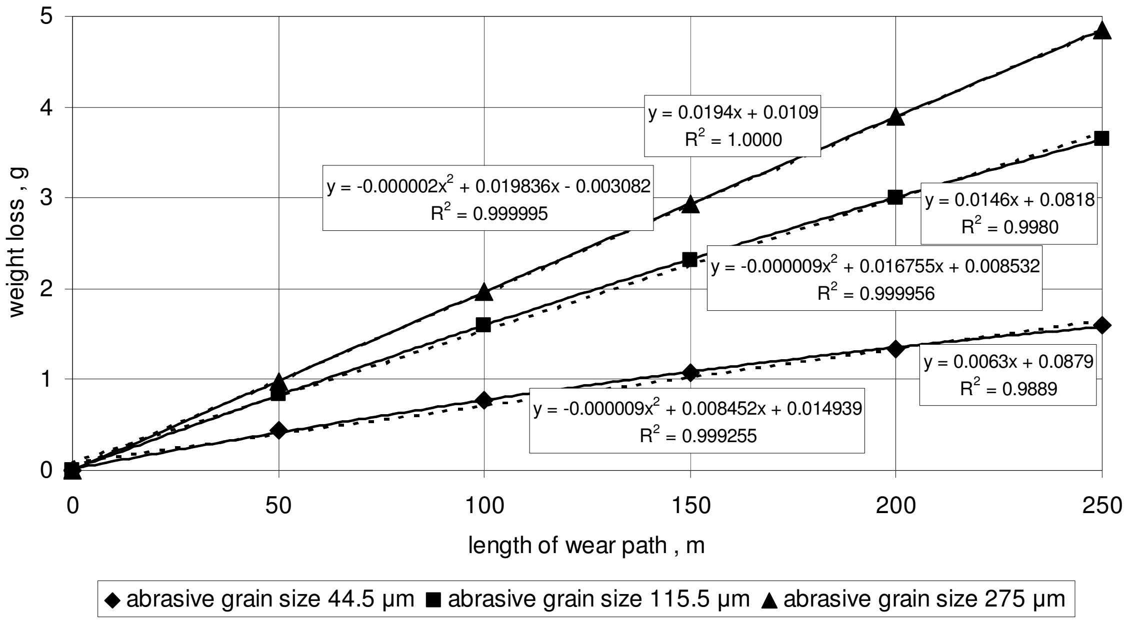

Fig. 4. **Abrasive cloth abrasiveness decrease during the test (PTFE)**

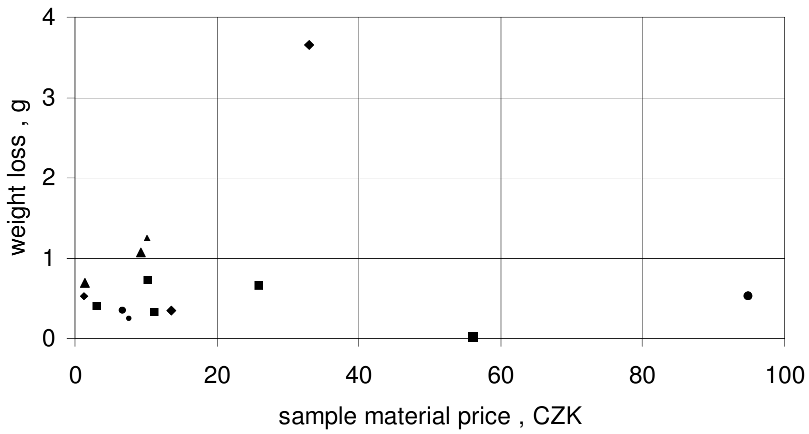

Fig. 5. **Relationship between weight loss and sample price (abrasive grain size 115.5 µm)**

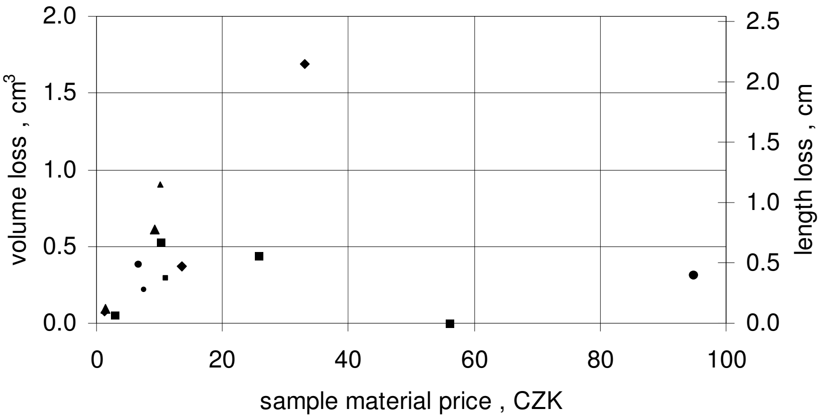

Fig. 6. **Relationship between volume/length loss and sample price (abrasive grain size 115.5 µm)**

As it follows from the above mentioned figures the results of the major part of the tested materials are located left at the bottom, but three samples considerably protrude from this location, namely

PTFE, PEEK and HSS Poldi Radeco 19 810. Using the abrasive cloth the plastic PTFE showed unequivocally the highest wear. The medium wear was determined at the most expensive plastic PEEK. On the contrary, almost zero wear was determined at the sample made from the relatively expensive high-speed steel HSS 19 810.

At the technical-economical assessing of the next sample results by volume (or length) wear the metallic materials, which means grey iron, structural steel and cast steel, have considerably higher wear resistance compared with all tested plastics and their price is low. But at the assessing using weight loss the metallic materials have higher losses than some plastics. It is caused by the considerably different density of these materials.

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

At the end it is necessary to emphasize that at plastics usually other properties are appreciated than wear resistance. For their application, e.g., mechanical, physical, chemical and technological properties are demanded.

Conclusion

The contribution contains the laboratory tests results of abrasive wear resistance of selected plastics and Fe alloys using the pin-on-disk machine with abrasive cloth carried out according to the standard CSN 01 5084. In total 10 types of plastics from one producer and 4 different Fe alloys (grey iron, structural steel, wear resistant cast steel and high-speed steel) were tested.

All samples were of a cylindrical shape of 10 mm diameter and 70 mm length. For the test samples wear three abrasive clothes of different grit, namely 240 (mean abrasive grain size 44.5 µm), 120 (mean abrasive grain size 115.5 µm) and 60 (mean abrasive grain size 275 µm) were used. The test of all materials was carried out according to the standard CSN 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 a new abrasive cloth was always used. The wear intensity was evaluated by volume loss, weight loss and length loss at all tested samples. The technical-economical evaluation was a part of the carried out tests.

From the carried out test results it follows that all plastics were excessively worn out regardless of their price. By this reason they cannot be recommended for such working conditions. In accordance with the precondition the highest abrasive wear resistance was determined at high-speed steel, but its price is relatively high. The results of the other Fe alloys were favourable, better than the results of plastics, even at a very low price. Contemporarily it was proved that with increasing of the grain size the wear intensity increases, even when at different materials differently.

References

1. ČSN EN ISO 1043-1 (64 0002) Plasty (Plastics) - Značky a zkratky (Symbols and abbreviated terms) - Část 1 (Part 1): Základní polymery a jejich zvláštní charakteristiky (Basic polymers and their special characteristics). 2012. In Czech.
2. Kinney, G. F. Engineering properties and applications of plastics. New York: Wiley. 21957. 78 p.
3. Lever, A. E, Rhys, J. A. The properties and testing of plastic materials. 3rd Ed. Bristol: Wright Temple Press Books, 1968. 445 p.
4. Pluhař, J. et al. Nauka o materiálech (Material Science). Praha: SNTL, 1989. 552 p. In Czech.
5. Brown, R. (Ed.). Handbook of Polymer Testing: Physical Methods. New York: Dekker, 1995. 845 p.
6. Budinski, K. G. Resistance to particle abrasion of selected plastics. Wear, 1997, 203-204. pp. 302-309.
7. Kutz, M. Applied plastics engineering handbook: processing and materials. Waltham: William Andrew, 2011. 644 p.

8. Štěpek, J., Zelinger, J., Kuta, A., 1989: Technologie zpracování a vlastnosti plastů (Processing technology and plastics properties). Praha, Bratislava: Nakladatelství technické literatury: Alfa, 1989. 637 p. In Czech and Slovak.
9. ČSN 01 5050. Opotřebení materiálu (Wear of materials). Názvosloví (Terminology). 1969. In Czech.
10. Vocel, M., Dufek, V. et al. Tření a opotřebení strojních součástí (Friction and Wear of Machine Parts). Praha: SNTL, 1976. 376 p.
11. Blau, P. J. ASM Handbook, Volume 18 - Friction, Lubrication, and Wear Technology. ASM International. 1992. Online version available at: http://app.knovel.com/hotlink/toc/id:kpASMHVFL2/asm-handbook-volume-18
12. Friction and Wear Testing. American Society for Testing and Materials. West Conshohocken, PA: American Society for Testing and Materials, 1987. 186 p.
13. Vocel, M. Experimentální metody hodnocení tření a opotřebení (Experimental Methods of Friction and Wear Evaluation). Kovové materiály (Metallic materials), 1983, 21, No. 6, pp. 711-722. In Czech.
14. 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.
15. 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.
16. Brožek, M.: Selected plastics wear resistance to bonded abrasive particles compared to some ferrous materials. Acta Univ. Agric. et Silvic. Mendel. Brun., 2014, 62, ….. (in press).
17. Brožek, M.: Layer number influence on weld deposit chemical composition. In.: 10th International Scientific Conference Engineering for Rural Development. 26.-27. May, 2011. Jelgava, Latvia University of Agriculture. pp. 393-397.
18. Brožek, M. Technicko-ekonomické hodnocení aplikace návarů u plužních čepelí (Technical-economical evaluation of the overlays application on the plough shares). Acta Univ. Agric. et Silvic. Mendel. Brun., 2007, 55, 4: pp. 129-136. In Czech.
19. 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.
20. Cieslar, J., Brožek, M., Bednář, B. An experimental assessment of special metal castings in reducing abrasive wear. Manufacturing Technology. 2013, 13, (4), pp. 423-428.