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ABRASIVE AND EROSIVE WEAR OF TECHNICAL MATERIALS

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Abstract

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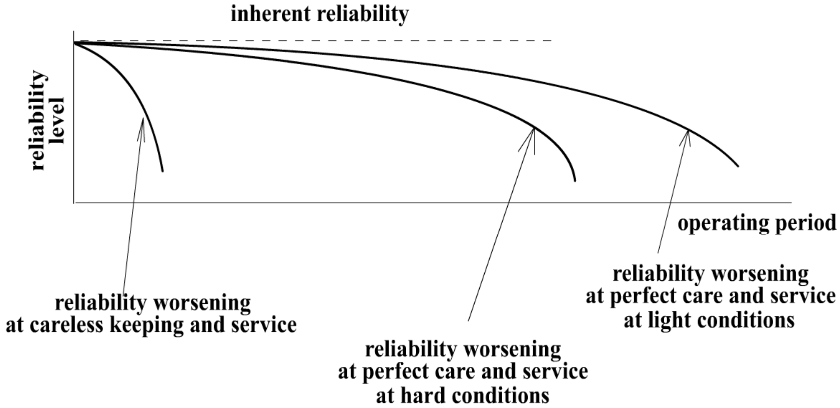
Operating reliability of agricultural, transport and construction machines is in a considerable degree influenced by corrosion and wear. These sorts of damage significantly influence the costs for the restoration of mechanical components, as well as their service and repairs. This article deals with comparing the abrasive and erosive wear of technical materials (soft steel, wear-resisting steel, ledeburitic cast-iron, cemented carbides). A test of the abrasive wear by means of bound particles was carried out on an apparatus with a corundum abrasive cloth. The erosive wear was made in a testing mechanism manufactured by the firm Kovo Staněk Ltd., which simulated the operating conditions by jetting with both spheroidal granulate and angular crushed material.

The comparative resistance against the abrasive wear of the tested materials varied by three degrees. The testing conditions and the working means affected not only the wear formulated in absoulute units (g, mm^3), but also the proportional resistance against the wear, which could be changed by a degree. According to these results, appropriate materials for the inside lining of the working chambre and for the casting wheel paddles of the jetting appliance could be found.

abrasive wear, erosive wear, laboratory test, operating test, abrasive cloth, jetting mechanism

The inherent machine reliability is given by its structural solving, by its way of manufacturing and by observing the technological discipline in production (Legát *et al.*). The level of machine operating reliability is also formed by the way of working use and by the system of machine maintenance (Fig. 1).



1: *General time process of the machine reliability level*

The chosen construction material and its resistence against the abrasive and erosive wear can significantly cause the inherent machine reliability.

In agriculture, enormous wear of machine works occurs especially in soil cultivation. A very good example of wear mentioned above is abrasive wear of ploughshares. The issue to be taken into consideration is the way of heat treatment, which makes a compromise between hardness and persistence. Carbon closed in iron grid α causes high internal stress within the material, which rather results to high hardness, but to a big loss of toughness, and thus to a higher risk of cleavage fracture and subsequent fragmentation of ploughshares (Votava *et al.*, 2005).

The abrasive wear is described as the separating of material particles from the functional surface by the harder and rougher surface of another body, or by abrasive particles (Blaškovič *et al.*, 1990). According to mutual interactions at the abrasive wear, two basic types can be differentiated. The first one shows a wear due to the interaction of two bodies, most often of the particles and the functional surface, a typical example of it is the wear of components during soil cultivation (Fig. 2 a), row material mining etc. In soil cultivation, the amount of soil skeleton is one of the most significant factors of abrasive wear of ploughshares (Votava *et al.*, 2007). The other occurence shows a wear by the particles placed between two functional surfaces. This situation means an interaction of three bodies. In practice, this configuration can be met in various movable impositions (Fig. 2 b), at crushing minerals, etc.

In order to extend the period of using those machine parts operating in conditions of possible abrasion, different abrasion-resisting materials can be used, as e. g. wrought abrasion-resisting steel (XAR, Brinar, Dillidur, Durostat, Domex Wear, Fora, HARDOX, etc.), casting steel (Hadfield steel, chromium carbide steel), alloyed white cast iron, cemented carbide, technical ceramics, overlays (martensitic, austenitic, ledeburitic) etc. Hardened carbon steel with normal quality 11 700 (E360) has got twice as much resistance than etalon steel 12 014.20 (C06E) with 100 HV hardness (Suchánek *et al.*, 2007).

The erosive wear is a constantly undesirable change of the surface and dimensions caused by the mutual action of the functional surface and the wearing medium. It is shown as a removing of particles from the deteriorated surface by the mechanical impact, in some case accompanied with other influence as well, e. g. chemical, electrochemical, electric. The mechanism of an

a – plough share (Filípek, Černý, 2007) **b – piston (Pošta, 2002)**

2: *Examples of abrasive wear*

3: *Erosive wear of an air-blast blade*

outside wear is similar to the abrasive wear, i.e. it comes to rippling and trimming of the material. As typical for this erosive wear, a non-even damaging of the surface can be observed, which is waved, corrugated and damaged even in the cavities (Červený, 2008). The erosive mechanisms are also utilized in technological applications, e. g. in surface finishing by jetting (Fig. 3) and cutting materials with water jet with particles.

The effects of single factors on the erosive wear intensity are very important, namely on the shape, hardness, dimension and the quantity of solid particles, the impact velocity and angle, the hardness and the material micro-structure (Suchánek, 2006). Soft and ductile materials (anneal steel) are appropriate to be used by big impact angles, on the contrary, by small impact agles hard materials (hardened and low-relaxed steel, white cast-iron, hard overlays, cemented carbide, ceramics) seem better.

MATERIAL AND METHODS

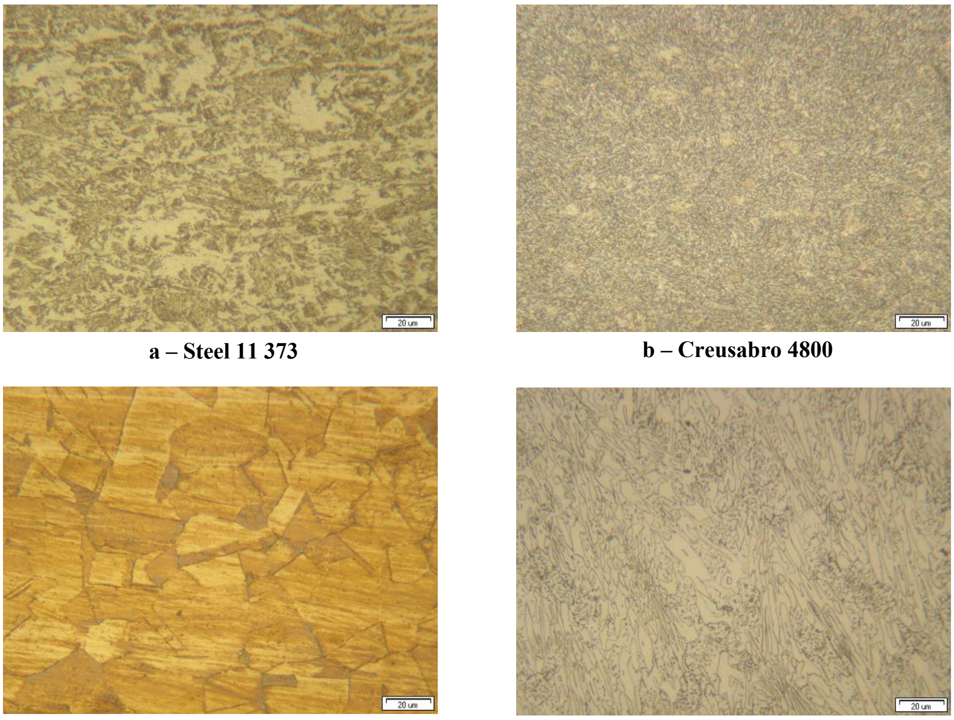
The wear was evaluated according to dimensional and mass decrease of three samples during the abrasive and erosive wear at laboratory and operative testing. The comparative resistance is related to the etalon made from low-carbon steel.

Probationary specimens

The resistance against wear was tested on six sorts of technical materials, the parameters of which can be seen in Chart I. Fig. 4 shows the micro-structure of some selected materials.

I: *Characteristics of tested materials*

Material	Characteristic	Density [g.cm^{-3}]	Hardness [HV10]	Prize CZK/kg
Steel 11 373 (S235JRG1)	Low-carbon ferritic-pearlitic steell	7.75	129	12
Creusabro 4800	Low-alloyed abrasion-resistant steel, heat-treated, oil-hardened (martenzitic-bainitic structure)	7.74	412	43
Creusabro M	Abrasion-resistant austenitic manganese steel treated by solvent annealing	7.70	280	74
Sedur 204	Material of throwing wheel blade (abrasion-resistant alloyed white cast iron)	7.34	803	300
K10	Cemented carbide (5% Co)	14.61	1 801	1 500
K20	Cemented carbide (6% Co)	14.62	1 752	1 500



a – Steel 11 373 **b – Creusabro 4800**

c – Creusabro M **d – Sedur 204**

4: *Microstructure of selected materials*

Jetting material

Two sorts of jetting material were used for an operative test (Trimeta, 2010):

- AMASTEEL S 230 – round granulate (Fig. 5 a)
  Round and heat improved granulate from hypereutectoid steel with sorbitic structure, hardness 40–50 HRC. Size marking S 230 responds to the accumulated proportion retained over testing sieves, mesh size: 1.00 mm – 0 %, 0.85 mm – max. 10 %, 0.60 mm – min. 85 %, 0,50 mm – min. 97 %.
- AMASTEEL LG 40 – sharp edged crushed material (Fig. 5 b).
  Crushed material from hypereutectoid steel with structure of the tempered martenzit, hardness 54–61 HRC, the edges of which are gradually rounded by jetting. Size marking LG 40 responds to the accumulated proportion retained over testing sieves, mesh size: 1.00 mm – 0 %, 0.425 mm – min. 70 %, 0.30 mm – min. 80 %).

Laboratory testing of the abrasive wear

The laboratory testing of the wear on abrasive cloth is based on the norm ČSN 01 5084 (Fig. 6). The tested sample is held in a holder and pressed by a weight to the abrasive cloth. During the testing, the horizontal disk with the abrasive cloth is rotated and the tested body is moved from the centre to the edging of the abrasive cloth. After the given length of the wearing course, the terminal switch will stop the machine. The specimens are the cleaned and the weight decrease determined by weighing.

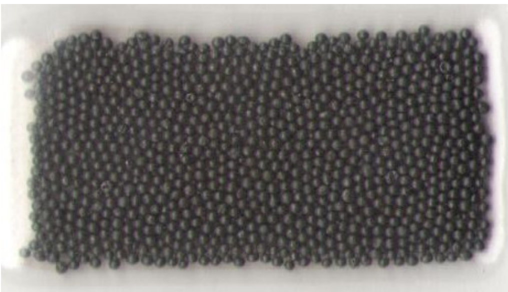
Proportional resistance against wear Φ was set according to relations:

$$\text{mass} - \Phi_m = \frac{m_{et}}{m_{vzo}}, \qquad (1)$$

where:
m_{et}.....mass loss of etalon or specimen [g]
m_{vzo}.. specimen weight decrease [g].

$$\text{Volume} - \Phi_v = \frac{\dfrac{m_{et}}{\rho_{et}}}{\dfrac{m_{vzo}}{\rho_{vzo}}}, \qquad (2)$$

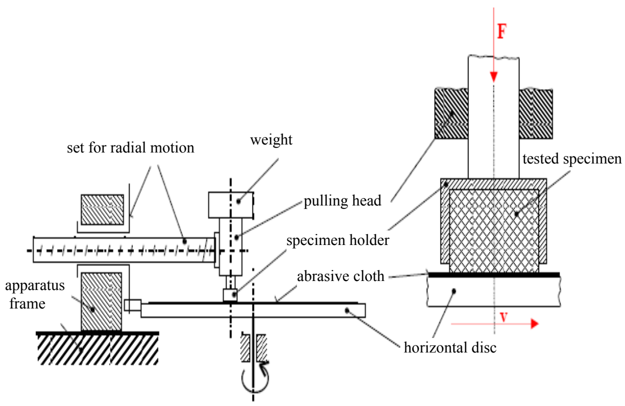
where:
ρ_{et}.....etalon density [g.cm^{-3}]
ρ_{vzo}...specimen density [g.cm^{-3}].



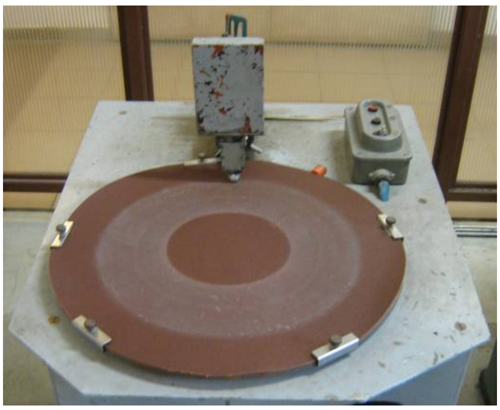
a – AMASTEEL S 230 – enlarged 2x

b – AMASTEEL LG 40 – enlarged 5x

5: *The used jetting material*



a – apparatus scheme



b – testing apparatus

6: *Laboratory test on abrasive cloth*

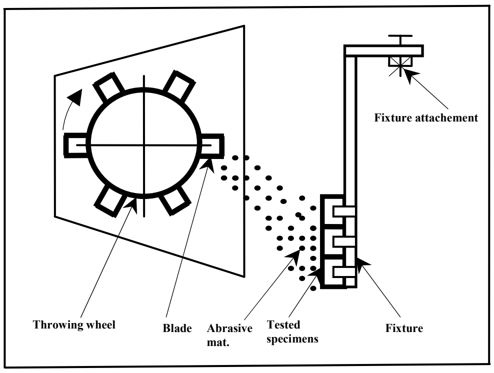
Conditions of the laroratory test:
- form of the testing specimen: cube 10 × 10 × 10 mm
- specimen number of each tested material: 3
- comparing etalon: steel 11 373 (S 235 JRG1) hardness 129 HV
- length of the friction course 250 m
- diameter of the revolving disc: 480 mm
- max. sliding speed of the tested body: 0.5 m.s^{-1}
- specific pressure: 0.32 N.mm^{-2}
- radial motion of the tested body: 3 mm.ot^{-1}
- abrasive cloth: corundum, granularity 120.

Operative test of the erosive wear

The tested specimens are fixed in a set installed in the working chamber of the jetting device (Fig. 7). The specimens are attached to the fixture by side clamp links. There are always three specimens of one tested material attached to the fixture. Then the abrasive material is thrown by the throwing wheel blades during the given test period, always broken by 30 minutes' pause after one hour's jetting onto the attached tested materials. After the end of throwing the abrasive material, the specimens are cleaned and the weight decrease is measured by weighing.

The proportional and weight resistence against the erosive wear Φ calculated according to the equation 1 and 2.

The conditions of the operative test:
- jetting mechanism type TZ 4–7,5~15/11–16, manufacturer – Kovo Staněk Ltd., Brumovice
- form of the tested specimen: prism 50 × 50 × 8 mm
- specimens number of each tested material: 3
- comparing etalon: steel 11 373 (S 235 JRG1), hardness 129 HV
- test period: 4 hours
- abrasive material quantity: 120 kg.min^{-1}
- throwing wheel efficiency: 7.5 kW
- circumferential speed of the throwing wheel: 55 m.s^{-1}
- diameter of the throwing wheel, used for this test: 359 mm
- number of blades on this throwing wheel: 6.



a – scheme operating test

b – jetting mechanism

7: *Operative test*

II: *Dimensional wear of tested specimen [mm^3]*

Tested material	HV 10	abrasive	erosive	
		abrasive cloth (250 m)	round granulate (4 h)	angular crushed material (4h)
Steel 11 373 (S235JRG1)	129	208 (192–225)*	8 474	6 128
Creusabro 4800	412	160 (158–162)*	609	1 845
Creusabro M	280	108 (106–110)*	107	321
Sedur 204	803	31 (29.4–31.7)*	22.5	52.3
K 20	1 752	0.388 (0.31–0.46)*	56.2	3.3
K 10	1 801	0.34 (0.34–0.34)*	37.8	2.6

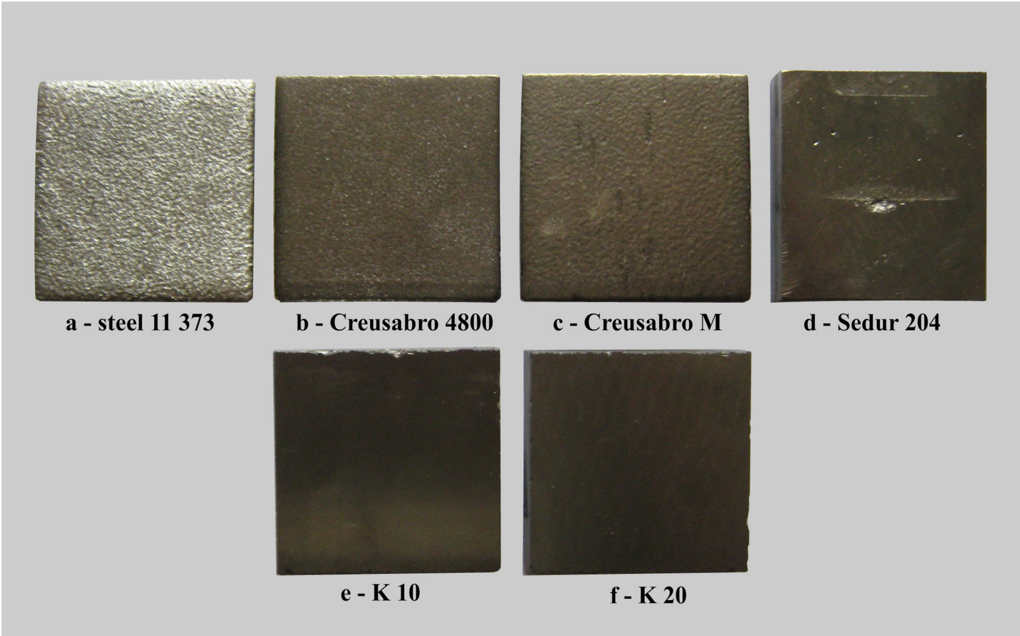
* confidence interval α = 0.05

RESULTS AND DISCUSSION

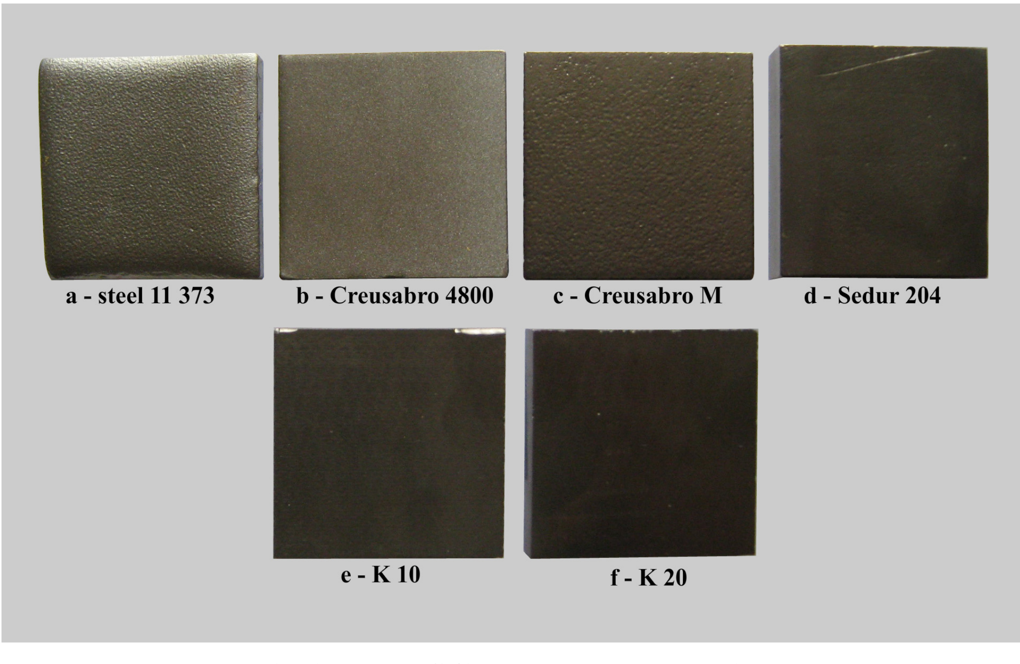
The average cubic decrease of tested materials is to be seen in Chart. II. The cubic decrease was lower at all tested materials and also when put in any othr medium than he etalon, i.e. low-carbon steel 11 373 (S235JRG1).

The weight decrease on the abrasive cloth was lowered when the hardness increased. However, the austenitic manganese steel Creusebro M seems is to be an exception, where the wear is lower than the corresponding hardness of the specimen.

The appearance of tested specimens after the operative test of erosive wear can be seen on Fig. 8. The wear is unequal, the highest decrease is placed next to the specimen edges, which is most perceptible at 11 373-steel. On specimens from cemented carbides K10 and K20, the round granulate broke mainly off the material particles



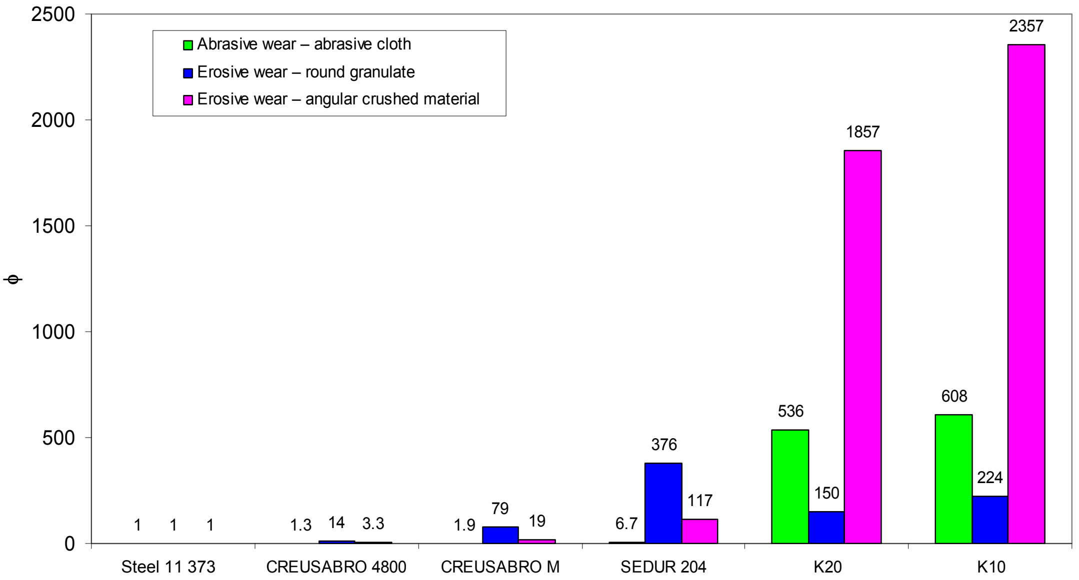
abrasive Amasteel S 230 – round granulate



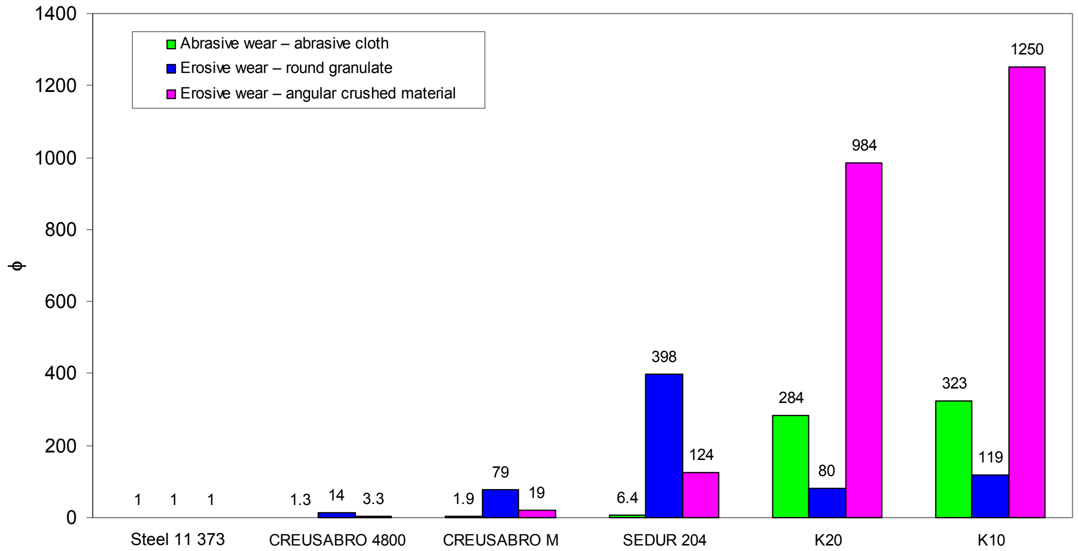
abrasive Amasteel LG 40 – angular crushed material

8: *Specimen appearance after operative test* near to the specimen edges, and therefore the wear is higher than at those ones made from alloyed white cast iron Sedur 204. As concerns angular crushed material, the wear is placed more equally on the specimens surface; the lowest cubic decrease can be seen at those made from cemented carbides.

Fig. 9 presents the values of the proportional and weight resistance against the abrasive and erosive wear for the tested materials, in comparison to the confronting specimen (steel 11 373 = 1). The intensity of the erosive wear is in the same time co-affected by many factors (impact velocity and impact angle, size, shape, hardness and quantity of erosive particles, carrying medium, physical-mechanical aspects and the micro-structure of eroded material). For instance, brittle materials are more resistent by small impact angles, on the contrary, the shapeable ones by large impact angles (Houdková *et al.*, 2003). Therefore, it is necessary to determine the resistance against the erosive wear experimentally (Suchánek, 2006).



a – cubic



b – weight

9: *Proportional resistance against abrasive and erosive wear*

SUMMARY

The wear is one of the most frequent causes that restrict the reliability and operating durability of machines and sets. This is influenced by many factors which can be tested both singly and in their mutual context. According to the laboratory as well as operative tests, the authors have reached following conclusions:

- to formulate the material resistence against wear in absolute units (mm^3, g) is not very clear and depends on test conditions. It seems more opportune to determine the relative resistance considering the selected etalon. In case of the different consistency of tested materials, it appears to be useful to set not only the cubic resistence, but the weight relative one as well;
- the relative resistance against the erosive wear by sharp-angular crushed material Φ was in cemented carbides (K10, K20) higher by three periods than in low-carbon steel, while the hardness is higher by one period only. Even if the price of cemented carbides is relatively high, their cautious use seems preferable, as the operating life of the machinery can substantially increase;
- if austenitic manganese steel (Creusabro M) is used, according to supposition, a favourable affect of the surface impact stress on the wear resistence is shown. In case of jetting with round granulate it makes Φ = 80; however, the resistence is much lower on the abrasive cloth and in sharp-angular crushed material;
- alloyed and abrasion-resistant white cast iron (Sedur 204) surprised by its high resistance against the wear through the round granulate (Φ = 330). In this surrounding it showed a higher resistance than cemented carbides, even if its hardness is half as high;
- low alloyed, heat treated and abrasion-resistant steel (Creusabro 4800) did not stand out by its resistance against wear. The structure modifications by special techniques of heat treatment did not distinctly increased the abrasion resistance. This steel was working better in operating tests than in the laboratory testing;
- the resistance against the abrasive wear on the abrasive cloth is adequate to the recorded hardness (Pearson corelation coefficient $r = 0.89$), even if the structure of the tested materials is very different. In case of the erosive wear, the impermeability is minor to the measured hardness ($r = 0.52$ – round granulate, $r = 0.61$ – sharp-angle crushed material);
- there is a very tight corelation ($r = 0.97$) between the extent of erosive wear by round granulate and by sharp-angle crushed material;
- the results from the operative test in sharp-angled abrasive material correspond better with the results of abrasive wear on abrasive cloth, as the hard particles are similar in their features.

The erosive mechanisms are used in treating the surface through jetting (Suchánek, 2006); however, an erosive effect on the jetting set itself is undesirable. On the basis of laboratory and operative test results it can be observed that the most suitable material for the inside casing of the jetting chambre seems to be Creusabro M, which is an abrasion-resisting austenitic non-manganese steel. The increase of resistance against wear is attached to the transformation of the metastable austenite on the martenzite during the jetting.

As long as our choice of material for the throwing-wheel blades would be based on the results from the test ČSN 01 5054 (Czech Norm) only, i. e. from the resistance on abrasive cloth, so it can be said that definitely the most resistant materials seem to be the cemented carbides K10 and K20. However, in an operative test with the round granulate, it was the white abrasion-resistant cast iron Sedur 204 that is the best material resisting the erosive wear. When compared with cemented carbides, it is more resisting, cheaper and it has the half density. In case of using the sharp-angle crushed material, Sedur 204 as well as the cemented carbide K20 can be recommended for the throwing-wheel blades.

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