ANALYSIS OF THE PROCESS OF ABRASIVE WEAR UNDER EXPERIMENTAL CONDITIONS*

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The paper brings evaluation of selected materials regarding wear resistance under conditions of a chosen experiment. The following materials were selected for the experiment: steel C 45 in state after heat treatment and steel C 45 in state after quenching and tempering. The selected materials were compared to weld deposits C 508 and C 64 using three different techniques after being welded on and heat treated. The tribological experiment was performed on test device, which belongs to the category of "pin-disk" test devices. The resistance of the selected materials was evaluated regarding energy consumption in the process of wear and it was compared to with sizes of weight loss. It was observed that combination of materials C 508 + C 64 in the 1st group of samples and material C 508 in the 2nd one gave the best results. Regarding the energy consumption in the process of wear, the best results were obtained in basic material and in combination of materials C 508 + C 64 in state after hardening.

pin on disk test; intensity of wear; abrasive wear resistance; hardness

INTRODUCTION

Hardfacing has been widely used in mining, minerals industry, and agriculture because of excellent abrasion resistance (Horvat et al., 2008; Chotěborský et al., 2009). Microstructure of hardfacing after weld depositing consists of hypoeutectic, eutectic, hypereutectic, martensitic, bainitic or equlibrium microstructure (Atamert, Bhadeshia, 1990; Chotěborský et al., 2007).

Friction as an important physical effect requires a lot of theoretic and experimental work to be understood (Vocel, Dufek, 1976). Systemic approach is necessary for the complex solution of friction and related attrition both in theoretic and experimental sphere. Regarding tribological properties of materials, the right choice of material or material pair, geometric shape, roughness, etc. are important (Brendel et al., 1978; Kučera, 2008). As concerns tribometry, it is a question of the test device, choosing own test methods as well as the right shape and size of the test samples, preparation of the samples, etc. (Kučera, Pršan, 2008, Kadnár et al., 2011; Rusnák et al., 2011). Choosing appropriate approach to resolve the adhesive friction problem and related wear is also very important (Czichos, 1978; Kadnár, Rusnák, 2008).

The energy required to separate a particular friction exposed material is a critical factor affecting the processes of friction and wear. It is therefore appropriate to assess these processes using the energy balance equation. A method for determining erosion wear has been developed from the quantitative assessment of friction and wear processes in energy terms (Brendel et al., 1978). The advantage of this energy method is the generality of the results. This method can be easily applied parallel to the molecular mechanical theory of Kragelsky. The core of the problem of the wear energy theory is the determination of density of friction energy (Fleischer, 1973; Blaškovitš et al., 1990).

The problem is even more complicated if the worn surface needs to be renovated.

As we deal with the tribological node with weld deposits, there are increased demands on the knowledge of material properties, the effects of alloying elements, and impact of welding technology on the welded layers properties (Blaškovitš, Čomaj, 2006; Kadnár et al., 2010).

The contribution deals with the prediction of properties of selected materials on the basis of tribological experiments results. The objective of the article was to assess selected materials in terms of wear resistance (as well as energy) and to compare results obtained in the basic material with those in the welded material.

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MATERIAL AND METHODS

When selecting a method for testing and evaluation of experimental results, the extreme work conditions of agricultural machinery functional parts used for soil processing was taken into account. On this basis we decided for the abrasive wear tests on the grinding cloth.

The tests were performed on the test device with grinding cloth (Figs. 1 and 2), which belongs to the category of "pin-disk" test devices with surface contact of the friction node elements. The test device is suitable for comparative tests of selected materials (Table 1). The test principle is that pin-shaped samples (test particles) are loaded with constant force and pressed to the grinding cloth on the rotating disk (Table 2). The pins were made of C 45 material and corresponding below listed weld deposits (Table 3). In accordance with the standard, the etalon was made of DIN RFe100 material (reference material).

Material C 45 in state after quenching and tempering is also often used for manufacturing soil processing tools. Depending on soil conditions, these tools usually operate under conditions of intense abrasive wear (Balla, Škarbala,1990; Čičo, Bujna, 2011).

Welding of the samples was performed on experimantal welding equipment ENZ-100 (VÚPT, Rovinka, Slovak Republic) in a shielding atmosphere of CO_2. The samples for abrasive wear resistance test were welded on a 105 mm diameter bar made of C 45 material using single-wire and two-wire rotation welding process method. Two-wire arc welding and welding with a cold wire addition were selected as welding methods. 20–25 mm long weld deposits were welded on for each sample. After cooling, the samples were lathed into ring shape, which was then divided into 12 parts. Another lathing prepared the active part of the sample which was imbedded into counterpart and pasted. The thickness of the weld deposit on the facial surface after completion was 2 mm. Testing specimens were prepared from each weld deposit. After heat treatment, the specimens were modified (as shown in Fig. 3.) and lathed to the final diameter.

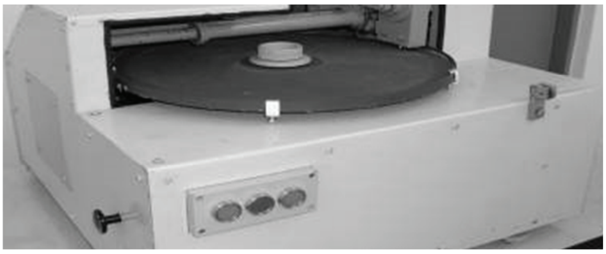
Fig. 1. Test device

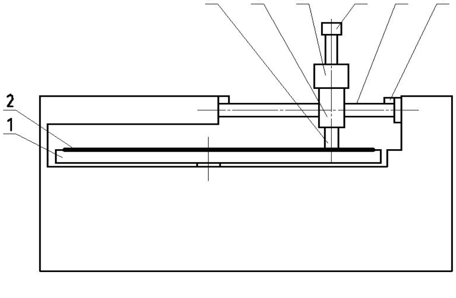

Fig. 2. Illustration of working principle
1- disk; 2- grinding cloth; 3- test particle; 4- holder; 5- tensiometer; 6- motion screw; 7- limit switch; 8- weight

This method of sample preparation (although very difficult) guarantees that the active surface of the sample, especially on welded layers, shall take the utmost match to the real surfaces (in terms of its properties).

The weight of the samples was evaluated before and after the test. The samples were weighed on MEOPTA analytical scales (Meopta, Přerov, Czech Republic) (accuracy 0.0005 g) after thorough degreasing and drying.

In accordance with the standard (STN 01 50 84, 1973):

$$\psi = \frac{\Delta m_e}{\Delta m_{vz}} \tag{1}$$

where:
Δm_e = mass loss of reference material (standard) (g)
Δm_{vz} = mass loss of sample (g)

Besides the mass losses, the size of the friction force was measured and recorded as well. Total friction work consumption as well as other indicators were determined based on the size of the friction force.

The density of friction energy represents the amount of friction work in relation to a friction stressed-amount of mass (Fleischer, 1973; Brendel et al., 1978).

Adding the mean shear stress and replacing the friction stressed-amount of mass with removed mass we get equation for calculation of the apparent density of friction energy. Subsequently, transforming this expression we get the basic energy equation of wear

$$e_t = \frac{A_t}{V_t} \tag{2}$$

where:
A_t = friction work (J)
V_t = friction stressed amount

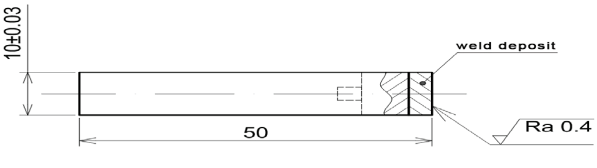

Fig. 3. Shape and dimensions of the sample with weld deposit

Table 1. The chemical composition of used materials is as follows (in weight %)

	C	Mn	Si	Cr	Ni	Cu	(P + S)
C508	0.25	0.9	0.9	-	-	-	-
C64	0.7	0.7	0.25	0.1	0.1	0.22	0.06
C45	0.45	0.65	0.27	0.25	0.3	0.3	0.08
DIN RFe100	0.06	0.45	0.15	-	-	-	0.04

If we add the mean shear stress $\bar{\tau}$ and replace the friction stressed-amount of mass V_t by removed mass ΔV, we get the equation for calculating the density of friction energy

$$e_t^* = \frac{\bar{\tau} s_t S_a}{\Delta V} \qquad (3)$$

where:
$S_a =$ nominal contact area (m^2)
$s_t =$ friction path (m)

Using the profilegram of the surface, the real contact area of the surface S_r can be determined from its geometrical characteristics.

Using the equation for the intensity of wear

$$I_h = \frac{\Delta V}{S_a s_t} \qquad (4)$$

and, subsequently, if we transform this expression we get the basic energy equation of wear:

$$I_h = \frac{\bar{\tau}}{e_t^*} \qquad (5)$$

The density of friction energy, the intensity of wear, and the mean shear stress are the indicators that rate the critical energy level which characterizes the friction process. The advantage of this energy method of wear process evaluation is the possibility of generalization of applicable results.

Table 2. Test parameters

Length of the friction path	50 m
Disk diameter	480 mm
Radial movement of the sample	3 mm
Specific pressure	$0.32\ N \times mm^{-2}$
Type of the grinding cloth	A99 – G

The intensity of wear is defined as the amount of material that is separated from the nominal contact area of a path. The individual groups of materials (wear products) can be compared under different conditions and times using the dimensionless intensity of wear. This comparison is possible from qualitative as well as quantitative viewpoints.

Hardness was measured on the faces of the samples, i.e. at the point of interaction with the test disk, using the durometer MEOPTA – VICKERS (Meopta, Modřany, Czech Republic) with a pyramid load F = 295.3 N.

The proportional resistance of the examined materials (ψ) is set as a criterion for assessment of the abrasive wear resistance test results. The density of the friction energy and the intensity of wear are the results of energy consideration and calculation. The density of the friction energy represents the amount of frictional work required to separate a certain amount of mass from the material.

Table 3. Heat treatment of samples for wear test

Sample no.	Additive material	Heat treatment	Surface hardness (HV30)	Mass loss (10^{-3} g)
1	C 508	Quenching 850°C/water,tempering 170 °C/1h./air	585 ± 29	180 ± 9
2	C 508+C64	Quenching 850°C/water,tempering 170 °C/1h./air	610 ± 12	154 ± 4
3	2 * C 508	Quenching 850°C/water,tempering 170 °C/1h./air	558 ± 25	165 ± 13
4	-	Quenching 850°C/water,tempering 170 °C/1h./air	626 ± 16	180 ± 5
5	C 508	-	384 ± 14	190 ± 10
6	C 508+C64	-	387 ± 14	196 ± 11
7	2 * C 508	-	300 ± 6	201 ± 4
8	-	Quenching 850°C/water,tempering 650 °C/1h./air	259 ± 3	204 ± 10

RESULTS

Microstructures of samples were martensitic (samples No. 1–4), ferritic and pearlitic (samples No. 5, 7, and 8), ferritic with tercial iron carbide (etalon), and bainitic with ferrite and pearlite (sample No. 6).

The results of the hardness and abrasive wear resistance test performed on the grinding cloth are shown in Table 3.

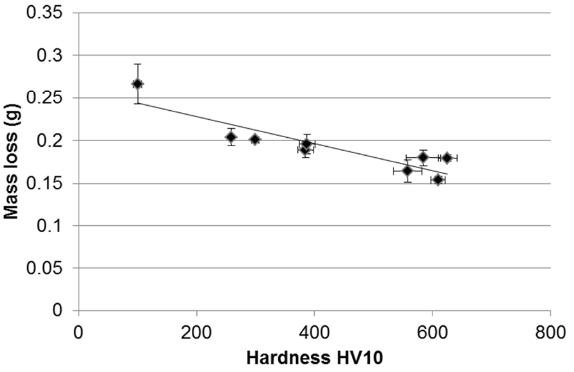

Fig. 4. Dependence between hardness and mass loss of tested samples

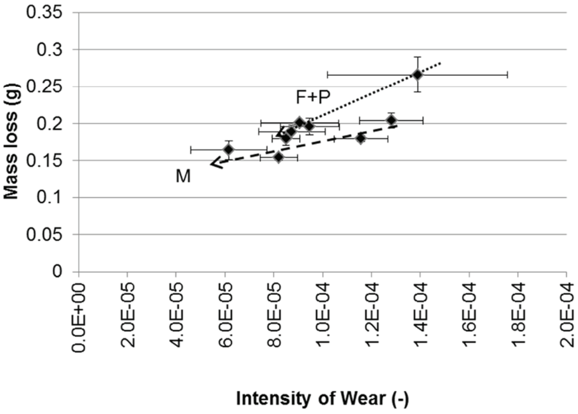

Fig. 5 Dependence between intensity of wear and mass loss of tested samples M – martensitic structure; F+P – ferritic and pearlitic structure)

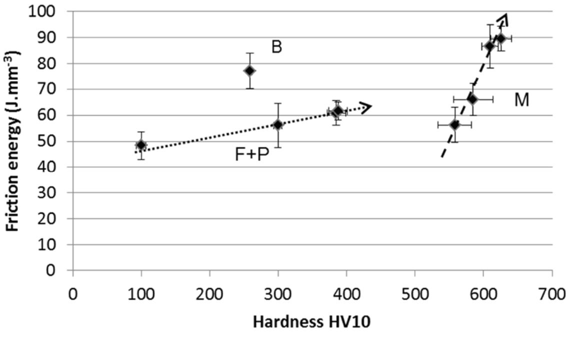

Fig. 6. Dependence between hardnes and friction energy of tested samples M – martensitic structure; B – bainitic structure; F+P – ferritic and pearlitic structure

Based on the results of the experiment and subsequent calculations, it is possible to compare the relative wear resistance with energy characteristics of friction process for each material. The samples are divided into two groups according to the heat treatment of the basic material. The first group is represented by samples with a martensitic structure after heat treatment and the second one by samples with an equilibrium phases into structure, i.e. ferrite and pearlite. The bainite structure contains equilibrium phases (ferrite and iron carbide), but their size in the structure is very small. This fact leads to the behaviour which can be observed at martensite.

DISCUSSION

The results indicate that the weld deposits samples attained higher values of relative resistance ψ than the basic materials. Hardness of the material was not decisive. Better properties of weld deposits given by heterogeneous structure of the surfaced metal were probably crucial. The layers created using two-wire technique had significantly better properties than the basic material in both groups.

Based on comparison of selected indicators, a very good mutual correlation of the results of the relative resistance ψ calculated from mass losses and hardness can be stated (Fig. 4).

The comparison of wear intensity I (Fig. 5) and the density of friction energy e^* points to the fact that sample No. 2 (weld deposit of C 508 + C 64 combination in state after quenching and tempering) has the second highest value of e^* (52.92 J.mm^{-3}) at the lowest intensity of wear. Sample No. 4 (material C 45 in state after quenching and tempering) has the highest value of friction energy density of the whole set of samples (54.508 J.mm^{-3}).

Comparing the density of the friction energy in different groups of materials, it can be stated that the highest value of e^* was observed in the basic material C 45 (in contrast to the relative resistance ψ) (Fig. 6). The highest value of density of friction energy was observed in sample No. 4 (basic material C 45 in state after qenching and tempering), followed by sample No. 2 (weld deposit of C508 + C64 combination in state after qenching and tempering) attaining to 96.9% of the size of sample No. 4. In the second group of samples, the highest e^* value was observed in sample No. 8 (basic material C 45 in state after qenching and tempering) followed by sample No. 6 (weld deposit of C508 + C64 combination without heat treatment) in which e^* made 79.6% of the value of sample No. 8.

It may be stated that layers made using this two-wire technique in both groups of used materials could have practical application in the worn surface recovery under conditions of intense abrasive wear. Welding on with the addition of a cold wire can create a layer higher resistant to specific conditions. Besides the mentioned technique, the quality of layers is also determined by the chemical composition of the materials used making it possible to create a sufficiently hard and resistant layers in the structure of the basic material.

CONCLUSION

The results of the present study revealed that the mechanical properties like hardness and abrasive wear resistance of hardfacing depend on hardness. Wear resistance can be indicated by the intensity of wear. Although it may seem that mass loses its independence directly on intensity of wear, near analysis of the structure showed that there exist relationships between structure and friction energy.

This observation can therefore explain the behaviour of the bainitic structure in abrasive wear conditions, when abrasive wear resistance of the bainitic structure is higher than that of martensitic one with the same hardness. This is due to the fact that the friction energy of the bainitic structure is higher than that of the martensite one in two body abrasion conditions.

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