Overlay materials used for increasing lifetime of machine parts working under conditions of intensive abrasion

M. Müller, P. Hrabě

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

Abstract

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We evaluated a degree of the machine part abrasive wear with secondary focus on their hardness. The paper states laboratory results of overlay systems from their wear resistance point of view. Laboratory experiments were carried out by two-body abrasion on bonded abrasive of a P120 granularity. The results proved an increased abrasive wear resistance of martensitic, ledeburitic and stellitic overlays against eleven different original products. The overlay UTP Ledurit 60 reached the optimum values. The GD-OES (Glow Discharge Optical Emission Spectroscopy) method proved the different chemical composition of the overlay from the stated chemical composition of the overlaying electrode.

Keywords: agriculture; chemical analysis; resistance; two-body abrasion; wear

Machines, their equipment and parts working under agriculture conditions are exposed to an intensive abrasive wear. Regarding the conditions and the intensity of the wear processes are integral part of the instruments lifetime and reliability as well as of the whole systems. High lifetime caused by low wear intensity of all functional parts and the reliability of the whole machine has to be reliably solved at machine parts which have to fulfil high requirements not only technological, but also the economic ones. High input costs of exchange parts lead to their renovation.

Huge number of machine equipment failures comes out from the wear of single parts. Also seizing of functional areas, which is caused by aggravated working conditions, causes the machine damage. Various constructional treatments can prohibit these failures in some cases (Aleš et al. 2010). However, sometimes the machine construction cannot be changed from constructional reasons. Then, it is necessary to choose a suitable material or properly prepare a surface of functional areas and edges (Chotěborský et al. 2008).

The wearing is very complicated physico-chemical phenomenon on its own (Vnouček 2001). The part stops having a predescribed size and shape as the consequence of the wear, the equipment becomes less effective and less reliable and a marginal status can occur when the machine is still working, then the machine fails (Rivlin 1984; Chotěborský et al. 2008). The abrasive wear is the most important type of the wear because it contributes to almost 63% of the wear costs (Jia, Ling 2007). One of very effective arrangements for increasing the wear resistance is the overlaying of functional surface with a suitable overlay material

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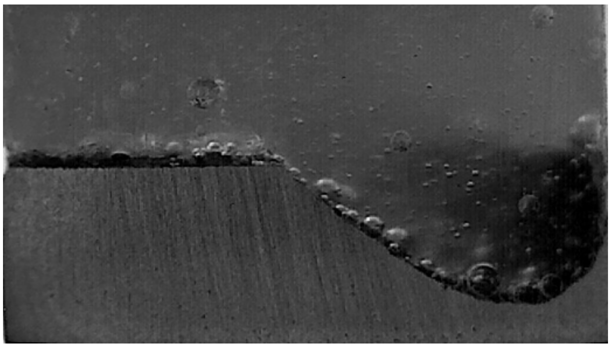

Fig. 1. Test specimen for abrasive wear testing

(Ellis, Garrett 1986; Pošta et al. 2002). Hardfacing is a commonly employed method to improve surface properties of tillage tools where an alloy is homogeneously deposited onto the surface of a base material by different techniques of welding, with the purpose of increasing hardness and wear resistance (Buchely et al. 2005).

The overlay materials used for this purpose are of various properties. When choosing the material we have to come out consistently from loading ways of an overlay part and to take into the regard a composition of a basic metal (Fernández et al. 2003).

Wear protection methods have the essential assumption that higher material hardness increases abrasion wear resistance, but the influence of material characteristics on wear is very complex and often depends on multiple impacts. To achieve optimal solutions for abrasion wear protection, investigations have to combine tribosystem analysis as well as laboratory and exploitation investigations (Horvat et al. 2008).

The abrasive wear in the agriculture and in the building industry is caused by the mutual interaction of the machine part surface and high abrasive environment in the form of the soil and minerals.

The soil is created by the quartz from the great part whose hardness ranges in the interval 900 till 1300 HV. Comparing with the iron alloys and their heat processing the quartz hardness is often higher and this shows itself negatively on the abrasive wear resistance (Suchánek et al. 2007).

The experimental study focused on the evaluation of the abrasive wear resistance of commonly supplied exchange parts of agricultural and building machines, i.e. a plowshare, a subsoiler, a wing of share, a skive, a part of seeding mechanism, a tooth blade of a dipper, a tooth blade of an excavator. When reaching the wear marginal state and above mentioned machine parts cannot fulfil their function the renovation by means of overlays is the effective solution. The experimental research focused also on the renovation by means of the martensitic, ledeburitic and stellite one-layer overlays with the evaluation of the abrasive wear resistance at the same time.

MATERIAL AND METHODS

The methodology for the evaluation of overlay materials and commonly supplied exchange parts of agricultural and building machines came out from the mutual comparison of the wear resistance and hardness.

Abrasive wear. The abrasive wear tests were carried out on a machine with an abrasive cloth distinguished for the high abrasivity coming out from the standard ČSN 01 5084 (1974).

The testing specimen with the dimensions 25 × 25 × 17.5 mm (Brožek, Nováková 2008) is held in the pulling head and it is pushed to the abrasive cloth of the granularity P120 by force induced by the weight set of total 2.35 kg. The testing specimen is moved from the edge to the centre of the abrasive cloth during the test and a part of its surface is constantly in the contact with unused abrasive cloth. The steel 12 014 (ČSN 41 2014, equivalent DIN: RFe 80) with the average hardness 100 HV was used as the etalon. Prepared testing samples and etalon were deprived of dirt by means of the acetone and then dried up (Brožek 2005).

The test principle corresponds to "two-body abrasion" when firmly bonded hard particles penetrate the surface and harder particles wear out softer material during the mutual motion of the particles. This process leads to the material separation and consequently to the mass and volume material losses.

The mass decreases were weighed on digital analytic scales weighing on 0.0001 g. The measurements were carried out repeatedly owing to reducing an inaccuracy and then statistically evaluated. The material resistance is evaluated with the quantity "relative abrasive wear ψ_h". The value in the graph is the arithmetic mean of three measurements. The relative wear was calculated according to the Eq. (1).

$$\psi_h = \frac{W_{hZP}}{W_{hZ}} \tag{1}$$

where:

ψ_h – relative abrasive wear

W_{hZP} – average mass decrease of etalon (g)

W_{hZ} – average mass decrease of tested specimens (g)

Table 1. Chemical composition of overlaying electrode (%)

Overlay material	C	Si	Mn	Cr	Mo	V	Nb	W	Co	Fe
UTP DUR 600	0.5	2.3	0.4	9.0	–	–	–	–	–	rest
UTP DUR 650 Kb	0.5	0.8	1.3	7.0	1.3	–	–	–	–	rest
UTP 670	0.4	1.0	1.0	9.5	0.6	1.5	–	–	–	rest
UTP 690	0.9	0.8	0.5	4.5	–	1.2	–	2.0	–	rest
UTP LEDURIT 60	3.2	1.0	–	29.0	–	–	–	–	–	rest
UTP LEDURIT 61	3.5	1.0	–	35.0	–	–	–	–	–	rest
CELSIT SN	1.6	–	–	29.0	–	–	–	8.5	rest	–
CELSIT 712	1.1	–	–	27.5	–	–	–	4.5	rest	–
CELSIT V	1.1	–	–	27.5	–	–	–	4.5	rest	–

rest – indicates residual amount of the element to 100%

Hardness according to Vickers. The hardness measuring according to Vickers was carried out in accordance with the standard ČSN EN ISO 6507-1 (2006). Tested loading was 294 N. The testing specimen surface was smooth, even, without scales, greases and any bodies. The surface roughness was R_a 4.63 ± 0.12 µm and R_z 21.67 ± 0.62 µm. The value presented in the graph is the arithmetic mean of ten measurements.

Testing samples – machine parts. The testing samples with the dimensions 25 × 25 × (3–7.5) mm from the plowshare, the subsoiler, the wing of share, the skive, the part of seeding mechanism, the tooth blade of a dipper, the tooth blade of an excavator were carried out by means of cut-off machines for dividing hard materials. Its advantage is the supply of huge amount of coolant so it does not come to excessive heating of the cutting area during cutting. The testing sample height 17.5 mm stated in the standard was not able to reach owing to the thickness of many machine parts. Required testing sample height was secured by means of the epoxy resin injected into the form of 25 × 25 × 17.5 mm (Fig. 1, Müller 2011).

Overlay material characteristic. Three basic groups of overlay materials (martensitic – UTP DUR 600, UTP DUR 650 Kb, UTP 670, UTP 690; ledeburit – UTP LEDURIT 60, UTP LEDURIT 61 and stellits – CELSIT SN, CELSIT 712, CELSIT V) divided according to a structure were used in the experiments. Chemical composition of overlaying electrode (Bohler Thyssen, Essen, Germany) is stated in Table 1.

Testing specimens – overlays. The overlaying of one-layer overlay was carried out by means of manual overlaying method with a covered electrode on plates with the dimensions 78 × 80 mm of material S235JR. The chemical composition of the hardfacing material is shown in Table 2. The deformation of the basic material occurred after the overlaying, so it was milled into a level on the side opposite the overlay. Then the overlay was ground into the level on a magnetic grinding machine with min. overlay material wasting and its heating affecting. At the end the plates were milled on the side opposite to the overlay to the height 17.5 mm. The specimens for the test were cut off with the dimensions 25 × 25 × 17.5 mm by means of the cut-off machine for dividing hard materials eliminating overlay heat affecting (its structure) (Brožek 2005).

The chemical composition of the overlays and the active machine parts was stated by means of the GD-OES method (Glow Discharge Optical Emission Spectroscopy).

RESULTS AND DISCUSSION

The laboratory experiment results showed different abrasive wear resistance of various parts and overlay materials. The hardness was also variable. The results in the Fig. 2 show that a direct proportion between the hardness and the abrasive wear resistance cannot be stated.

The results showed an increased abrasive wear resistance of martensitic, ledeburitic and stellite over-

Table 2. Chemical composition of the hardfacing material (%)

Fe	C	Mo	Cr	Si	Mn
97.39	0.23	0.04	0.05	0.32	1.08

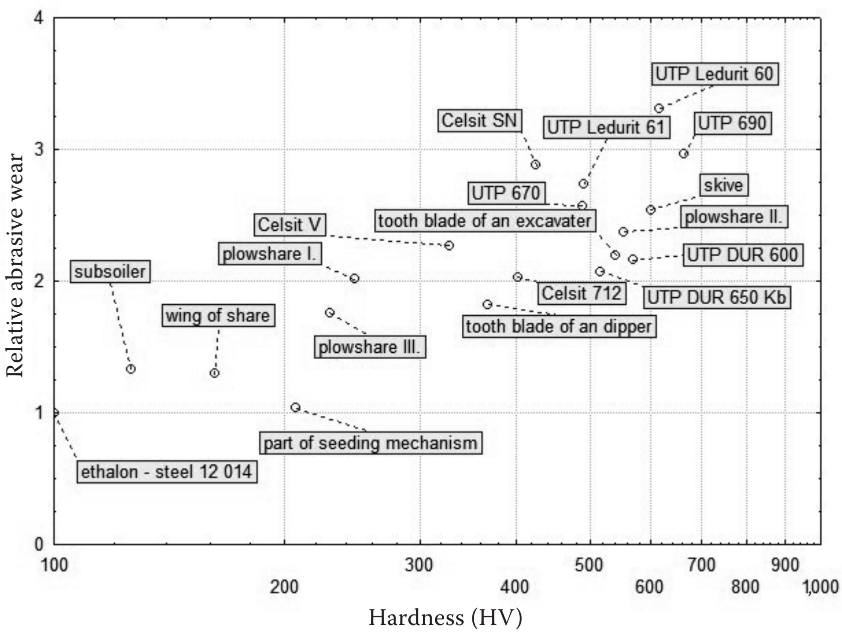

Fig. 2. Influence of hardness on relative abrasive wear resistance

lays against eleven different original products. The overlay UTP Ledurit 60 reached the optimum values.

Exchange parts of agricultural and building machine showed the abrasive wear resistance ca. 1–2.5. Also the hardness ranged in the interval 129–601 HV. When comparing the abrasive wear resistance results of agricultural and building machines it is necessary to take into regard the purpose of the usage and namely presses entering during the soil processing. The experimental results proved considerable differences when comparing three plowshares of different producers whose abrasive wear resistance differed considerably in the interval ca. 1.8–2.4 and the hardness 229–554 HV. The reason is the application of different materials by producers and namely the heat processing which is often of the basic influence.

The exchange parts of agricultural and building machines proved relatively low abrasive wear resistance. This is connected with the low lifetime in the operation. The effective renovation method is overlaying by means of suitable overlay materials. Overlay materials proved the wear resistance in the interval 2.03 to 3.31 and the hardness 328–664 HV depending on the type and the chemical composition. The martensitic overlays (UTP DUR 600, UTP DUR 650 Kb, UTP 670 and UTP 690) showed lower abrasive wear resistance than the ledeburitic overlay systems (UTP Ledurit 60 and UTP Ledurit 61). The carbon ranged in the chemical composition of the martensitic overlay materials in the interval 0.4–0.9%. The overlay materials UTP 670 and UTP 690 showed higher abrasive wear resistance against other martensitic overlays. Other alloying elements were the molybdenum, the tungsten and the vanadium. The ledeburitic overlay materials comprised high percentage of the carbon (3.2–3.5%) and of the chromium (29–35%). The results proved the influence of the abrasive wear resistance on the integrity of the tested material depending on the content of the carbon (carbides) and other alloying elements in the overlay structure. The price of the martensitic materials ranges from 8 to 20 €/kg, the ledeburitic materials from 16 to 28 €/kg.

The stellite overlay system Celsit SN showed better qualities than Celsit 712. The price of the stellite overlay materials ranges in the interval 100–130 €/kg. The stellite overlay is not suitable for the application in the agricultural production because of the considerable costs.

The costs of the exchange parts of the agricultural and building machine range ca. from 4 to 20 €/kg depending on the type and size. The consumption of the overlay material to one piece of renewed part moves in grams depending on the wear degree and on the overlay volume. The lifetime increase (Fig. 2) is more than 100% in some cases.

Table 3 presents the chemical composition of the overlays and the active machine parts. Comparing to the Table 1 it can be seen that the chemical composition mixes when applying the overlay systems. The addition of the vanadium and higher carbon concentration in the ledeburitic overlays showed themselves favourably with increased abrasive wear resistance. The vanadium and the tungsten shoved themselves positive to increasing the hardness in the testing overlay samples.

Table 3. Chemical composition of overlays and active machine parts found out by means of GD-OES method (%)

Overlay material	C	Si	Mn	Cr	Mo	V	Nb	W	Co	Ni	Fe
UTP DUR 600	0.55	1.68	0.38	6.98	–	0.01	–	–	–	–	rest
UTP DUR 650 Kb	0.29	0.68	1.10	5.29	1.07	–	0.41	–	–	–	rest
UTP 670	0.27	0.60	0.37	6.55	0.37	0.76	–	–	–	–	rest
UTP 690	0.89	0.66	0.31	3.56	–	0.98	–	1.13	–	–	rest
UTP LEDURIT 60	2.93	1.06	1.00	30.33	0.60	0.19	–	–	–	–	rest
UTP LEDURIT 61	2.04	0.76	0.13	26.31	–	0.10	–	–	–	–	rest
CELSIT SN	0.70	0.76	0.88	24.55	–	0.22	–	6.44	36.89	1.38	rest
CELSIT 712	0.68	0.70	0.17	24.03	–	0.27	–	7.64	39.66	0.70	rest
CELSIT V	0.70	0.40	0.40	20.89	–	0.12	–	3.04	32.03	0.40	rest
Active machine part											
Plowshare I.	0.54	0.16	0.76	0.02	–	–	–	–	–	–	rest
Tooth blade of an excavator	0.30	0.23	1.32	0.42	–	–	–	–	–	–	rest
Subsoiler	0.20	–	0.28	–	–	–	–	–	–	–	rest
Plowshare II.	0.24	0.26	1.11	0.87	0.12	–	–	–	–	0.09	rest
Plowshare III.	0.50	0.17	0.71	0.01	–	–	–	–	–	–	rest
Skive	0.13	0,22	1.35	0.17	–	–	–	–	–	–	rest
Part of seeding mechanism	2.36	2.06	0.42	–	–	–	–	–	–	–	rest
Wing of share	2.34	2.08	0.45	0.03	–	0.03	–	–	–	–	rest
Tooth blade of a dipper	0.13	1.68	1.31	0.88	–	–	–	–	–	–	rest

GD-OES – Glow Discharge Optical Emission Spectroscopy; rest – indicates residual amount of the element to 100%

The wear is the essential characteristic in the agricultural production owing to the loss of function of a given part caused by the change of the geometry, which is significant in this segment of the soil processing. The ploughing technology can be mentioned as the sample in which the wear causes an increase of the fuel consumption, decreases the labour effectiveness, the outage time and so on (Natsis et al. 2008). The above mentioned presumption defines definitely the priority of the research focusing on the possibilities of the abrasive wear resistance increase.

Horvat et al. (2008) during the operation tests focused on reducing the wear of a mouldboard plough share by means of overlaying came to the conclusion that lower fuel consumption and higher rate of the work in ploughing compared to regular shares were achieved with hard-faced plough shares. The operation tests of the tool wear are essential. Their limit is the influence of unexpected and variable soil conditions (Er, Par 2006). Sare and Constantine (1997) dealt with a development of methodology for evaluation of the abrasive wear resistance and they found out differences between laboratory and operation tests. They state that the conditions of the operation tests for evaluation of the wear factor are hardly reproducible whereas under the laboratory conditions the comparing continuity of single tests can be preserved. The problem of the particular material choice has to be studied more globally during the practical application. When processing the soil it is necessary to take into regard also the dynamic impact (the material toughness) which affects negatively the integrity not only of the surface layers. This authorized presumption led to focusing the experiments to the laboratory test method.

The laboratory test results correspond with the statement of Bayhan (2006) that the overlaying of the hard layer by means of the electrode is the efficient method for the wear lowering. Bayhan (2006) states that the wear rate is decreasing with the increasing ratio of carbon and manganese in the chemical composition of the edge. The results of the overlaying electrode chemical composition and the values of the chemical composition after the overlaying (during the mixing with the basic material at the same time) show that it comes to the change of the chemical composition. The results of the chemical composition of nine machine parts confirm the findings of Horvat et al. (2008) that they were produced from the carbon steel and the low-alloy steel.

Kishore et al. (2005) stated that the manganese decreases the carbide portion in the overlay layer and increases the chromium concentration. Bayhan (2006) came to the conclusion in his experiments that the overlaying electrode ELHARD 14Mn (Geko, Oiartzun, Spain) containing 13.5% of manganese had the lowest value of the abrasive wear resistance from the compared overlay materials although it comprised 0.6% carbon. According to the Bayhan (2006) results the electrode containing 0.5% carbon and 0.5% manganese reached the best values of the abrasive wear resistance. The laboratory tests proved that the manganese got into the overlay layer although the overlay chemical composition did not contain it – see UTP Ledurit 60 and 61 in Table 1.

CONCLUSION

In the paper are presented laboratory test results carried out by means of the two-body abrasion method of chosen agricultural and building machine parts, which are exposed to the intensive abrasion during their operation. Second group results are focused on the prospective renovation by means of overlay materials. The results are focused on the abrasive wear resistance evaluation of different parts and materials and the hardness evaluation at the same time.

– The results proved increased abrasive wear resistance of one martensitic (UTP 690), two ledeburitic (UTP Ledurit 60 and UTP Ledurit 61) and stellite (Celsit SN) overlays against common segments operating in the agriculture and industry.
– The results of the overlay chemical composition are different from the chemical composition of the overlaying electrode. It comes to the significant mixing of the structure.
– When the cost is taken into consideration, UTP Ledurit 60 (24 €/kg) and UTP 690 Kb (14 €/kg) electrode can be recommended for hardfacing.
– The lifetime of overlays is more than 100% higher than the lifetime of exchange parts in some cases.
– The economic point of view is the integral part of given problem solving in the technical practice, so it is necessary to solve the technical problem using suitable overlay material and with low costs on the whole overlaying process at the same time.

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Corresponding author:

Asc. Prof. Ing. Miroslav Müller, Ph.D., Czech University of Life Sciences Prague, Faculty of Engineering, Department of Material Science and Manufacturing Technology, 165 21 Prague, Czech Republic
phone: + 420 224 383 261, fax: + 420 234 381 828, e-mail: muller@tf.czu.cz