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APPLICATION OF HARD METAL WELD DEPOSIT IN THE AREA OF MIXING ORGANIC MATERIALS

Jiří Votava[1], Vojtěch Kumbár[1]

[1] Department of Technology and Automobile Transport, Faculty of Agronomy, Mendel University in Brno, 613 00 Brno, Czech Republic

Abstract

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Any machine part is subject to degradation processes. Intensive wear occurs either when two bearing surfaces come into contact or when loose particles rub the function surface of a machine part. Soil processing machines are a good example. A similar process of abrasive wear occurs also in mixing machines or lines for material transport, such as worm-conveyors.
The experiment part of this paper analyses hard metal weld deposit dedicated for renovation of abrasive stressed surfaces. In order to prolong the service life of a blade disc in a mixing machine Kreis-Biogas-Dissolver, the technology of hard surfacing by an electric arc was used. Tested hard metal electrodes were applied on a steel tape class 11 373. To eliminate mixing with the base material, weld beads were applied in two layers.
Firstly, the weld bead was visually analyzed on a binocular microscope. Further, weld bead as well as the base material was analyzed from the metallographic point of view, whose aim was to identify the structure of weld metal and the origin of microcracks in weld bead.
Moreover, there was also measured microhardness of weld metal. Abrasive resistance was tested according to the norm ČSN 01 5084, which is an abrasive cloth test. As in the mixing process also erosion wear occurs, there was also processed a test on a Bond device simulating stress of test samples by loose abrasive particles. The abrading agents were formed by broken stones of 8–16 mm in size. Based on the results of the individual tests, the recommendation of usage hard metal electrodes for prolonging service life of machine parts will be made.

Keywords: abrasive wear, hard metal, electrode, blade disc

INTRODUCTION

Wear causes up to 80% of defects of machines and their parts. Wear is the most common cause of defect, outweighing defects caused by breaks, cracks, deformations or other overloading of machine parts (Blaškovič *et al.*, 1990; Suchánek, *et al.*, 2007). Wear worsens functions of the device which can result in its lay-up or its total destruction (Vysočanská *et al.*, 2010). By its intent, losses caused by wear can be compared only to losses caused by corrosion (Stachowiak, 2005).

Abrasive wear of an active machine part causes a permanent change of its surface and size, which results in lowering the quality of working cycle (Paulíček, 2011). In the field of biogas production, abrasive wear is the question of preparation of homogenous medium, which is afterwards transported to a fermenter. Blade discs crushing raw materials are abrasively stressed in the area of maximal circumferential speed. It is a typical example of abrasive-erosive stress (Stachoviak, 2005; Stodola *et al.*, 2008).

Selection of an appropriate technical material is the base presumption eliminating degradation processes originating in abrasion. The inner microstructure resisting to dynamic influences and external forces is very important. The best results are reached by materials in which the microstructure is formed by primary carbides exempted in the base metal matrix (Bergman *et al.*, 1997; Badisch and Mitterer 2003; Kazemipour *et al.*, 2010).

At a high dynamic stress and due to a low tenacity of the material, a fragmentation may arrive. In the field of renovations of machine parts, carbide materials can be applied on a base material by an electric arc. The result is a highly quality wear-resistant surface with a tenacious kernel able to suppress dynamic strains of the environment.

MATERIAL AND METHODS

Characteristics of functional surfaces of tools and their parts can be modified without preserving the original characteristics of the base material beneath the surface. Hard surfacing belongs to classical methods which allow lowering of material and economic costs (Čičo *et al.*, 1990; Gahr, 1987; Kotus *et al.*, 2013). The principle is to create an abrasive-resistant surface preserving tenacity of the inner profile.

The experiment of this paper is focused on an analysis of hard metal electrodes used for renovation of stressed machine parts, namely for the mixing machine "Kreis-Biogas-Dissolver" (see Fig. 1). It is a device used for speeding, respectively optimizing a fermentation process in a biogas production.

The purpose of a dispersing machine is to produce a homogenous substrate which eliminates delays of fermentation processes. A blade disc, see Fig. 2, is the base function unit, which is able to mush perfectly an organic material, such as corn chopped forage, grass, in a liquid, such as slurry or water.

In the production process, there origin rotational flows which bring rough particles to the knife blades and cause intensive abrasive wear of the blade. The mixing process lasts 15–25 minutes; afterwards the substrate is sucked from the mixing machine and processed further. The blade disc is being considerably stressed both abrasively and erosively. Proper functioning of the whole mixing system is limited by the mentioned active unit. Eliminating intensive wear by application of hard metal on blades of blade discs is one of the possibilities to prolong its service life.

2: *Blade disc*

Characteristics of Tested Materials

- OK 8328: is a hard metal electrode dedicated to medium stressed machine parts. Base melting material is mainly alloyed by Cr. The advantage is tenacious weld metal, which can further come to a cutting operation. This material is being used for renovations of shafts and cogwheels.
- OK 8350: is a suitable material for renovations of worn parts of agricultural machines, such as soil processing machines. According to the chemical composition it is a material alloyed by Cr and Mo. It is necessary to preheat the electrode at ca. 250 °C before its application on worn part.

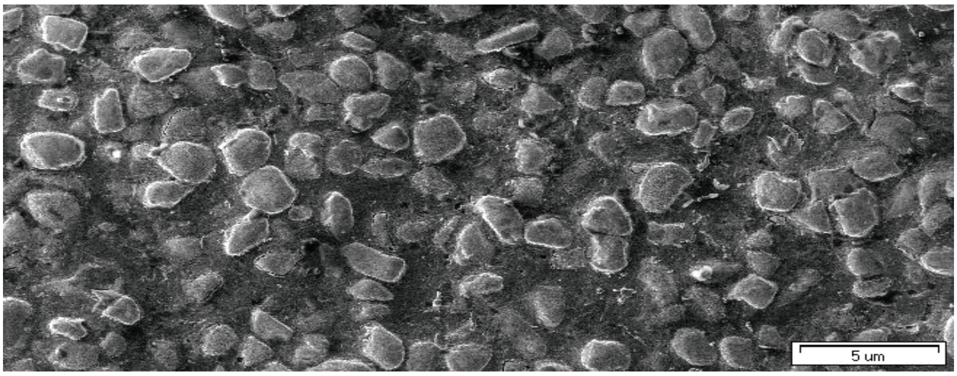
1: *Mixing machine Kreis-Biogas-Dissolver*

I: *Chemical composition of weld metal*

Tested materials	Hardness HRC	Chemical composition of tested electrodes				
		C	Si	Mn	Cr	Ti
OK 8328	28	0.1	0.7	0.7	3.2	-
OK 8350	51	0.4	0.4	0.7	6.0	-
E-B 511	48	0.2	0.3	0.6	13.0	-
OK 8478	57	4.5	0.8	1.6	33.0	-
OK 8484	60	3.0	2.0	0.3	6.3	4.8

II: *Chemical composition of metal coatings*

Spectrum	C [$\%_{wp}$]	Mn [$\%_{wp}$]	Si [$\%_{wp}$]	Mo [$\%_{wp}$]	Cr [$\%_{wp}$]	V [$\%_{wp}$]	Ni [$\%_{wp}$]	Fe [$\%_{wp}$]
Middle part	0.34	1.8	0.13	0.09	1.35	0.10	0.41	95.27
Active blade	0.33	1.6	0.18	0.11	9.3	0.12	2.15	86.18



3: *Accumulation of chrome carbides on a blade of a blade disc*

- E-B 511: is a suitable material for welding functional surfaces wear resistant to dynamic loads. Tenacity of weld metal guarantees also usage in renovations of valves or blades of chippers. Weld metal itself is able to resist temperatures up to 400 °C. Weld deposit is usually not processed afterwards.
- OK 8478: is declared for depositing active parts of ground machines which are subject to a high abrasion by sand, gravel and other minerals. Weld deposit resists corrosion forces up to 1,000 °C. Renovated part has to be preheated at ca. 500 °C. Weld deposit is not been processed afterwards.
- OK 8484: provides weld metal with a high share of small carbides in a martensite matrix. Weld metal resists to intensive abrasive strains of minerals. Optimal hardness of weld metal is guaranteed in the first layer of weld deposit. Weld metal is minimally mixed up with the base material. Preheat of 200 °C is necessary.

In order to find out the optimal electrode for renovation of a blade disc, the electrodes were subject to laboratory tests. The diameter of electrodeswas 2.5 mm, welding current was 60 A. To minimize the influence of mixing up with the base material, the samples were deposited in two layers. Chemical composition of the weld metal is given in Tab. I.

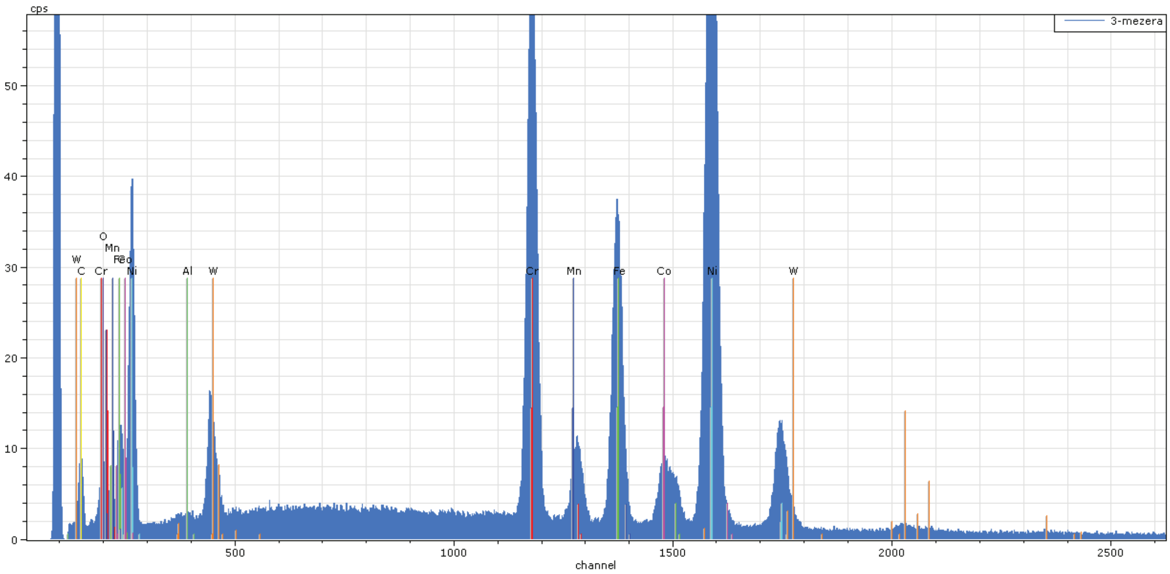
Characteristics of Base Material of the Blade Disc

Blade discs are made of steel with a high tenacity, a good tenacity and an increased resistance to fragile failure. Average hardness of a blade disc was 27 HRC. Corrosion resistance is appropriate to the working environment.

Analysis of Element Composition of the Metal Coating

A scanning electron microscope VEGA II XMU (produced by the company Tescan) was used for the microanalysis of the elemental composition, in conjuction with energy dispersive microanalyser QUANTAX 800. The measurement of the elemental composition of a sample was performed on three different pads using the multiplication 100 times. The accelerating voltage equalled 15 kV. The readings are equal to mass concentration of 100%. The results of the chemical composition of the individual metal layers gained are presented in Tab. II and they show the average value obtained out of three measurements.

In the active part of the blade disc, there the EDS analysis identified accumulation of chrome carbides (see Fig. 3), which is a very low-quality coating which does not for a compact surface on the blade of a blade disc. Carbides are filed in a metal matrix,



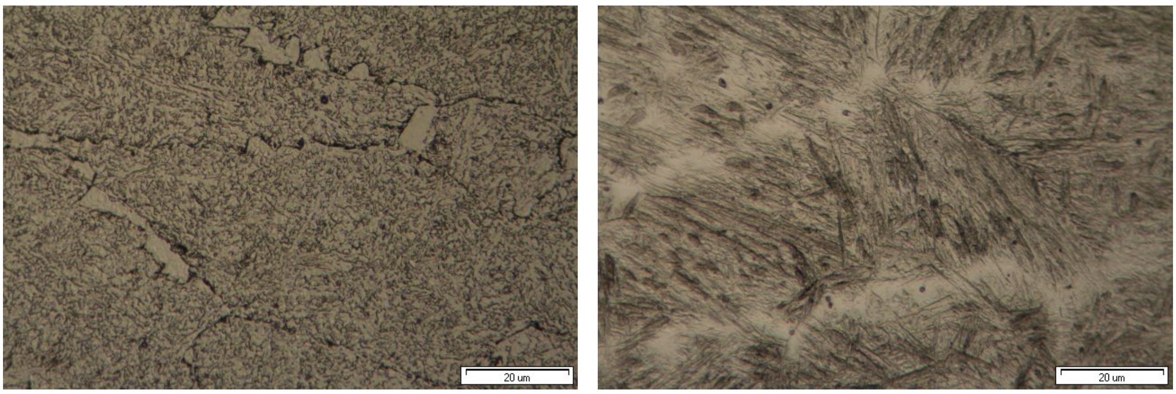
4: *EDS spectrum of an active blade of a blade disc*

in which were afterwards observed traces after these carbides.

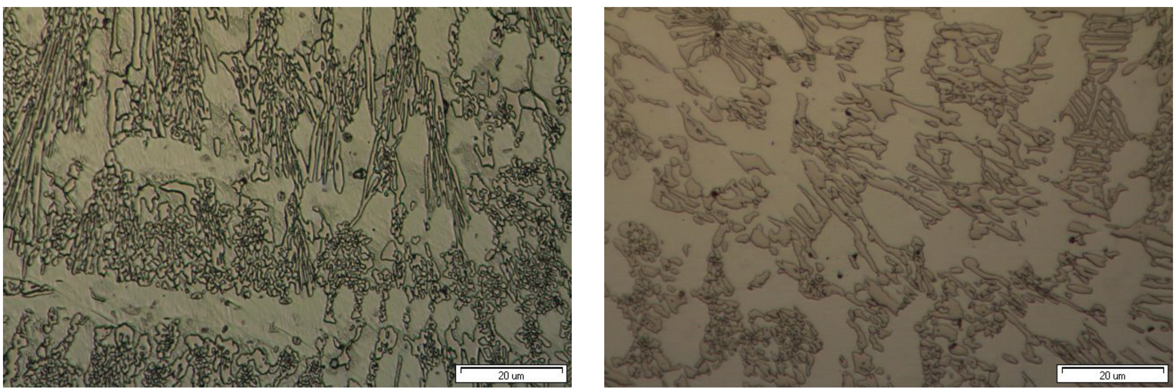
The quantitative analysis used the intensity of the line drawn by the individual chemical elements (see Fig. 4), which serve for the evaluation software purposes.

Metallographic Evaluation of Applied Coatings

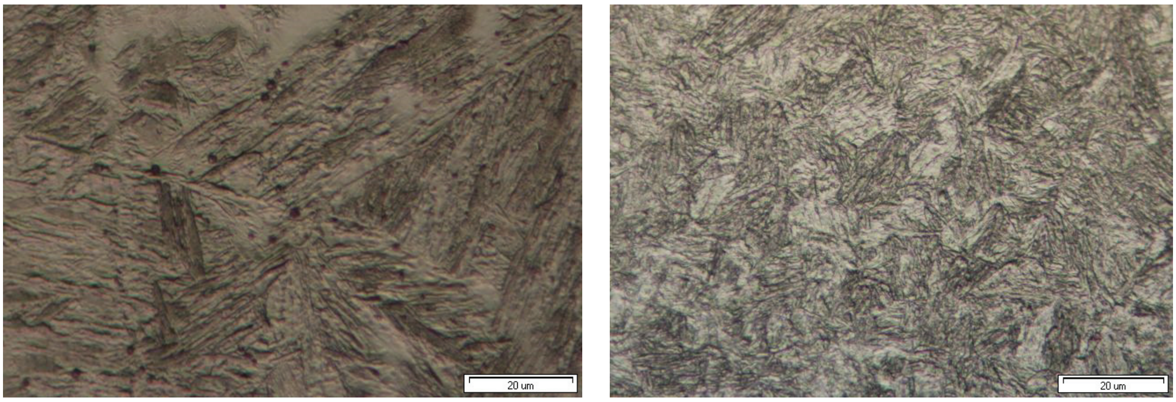
In order to prepare metallographic samples, methylmetaacrylate casting resin was used. Metallographic evaluation was processed on a metallographic microscope Neophot 21 and software analySIS for deduction of length



5: *Weld depositOK 8328 (left) and OK 8350 (right)*



6: *Weld depositOK 8478 (left) and OK 8484 (right)*



7: *Weld depositE-B 511 (left) and structure of the base material (right)*

parameters. According to the processed metallographic scratch patterns it is possible to evaluate not only the individual structural phases of the weld deposited materials but also the quality of carbide delamination and the origin of microcracks during the process of deposition. Microstructures of the tested materials can be seen in Figs. 5–7.

As is it apparent from the Fig. 5, chemical composition of a coated electrode primarily determines morphology of structural phases in a welded metal. Welding electrodes of type OK 83xx are characterized by the amount of carbon. More carbon in the structure means that the structure passes from a ferritic-sorbitic structure to a martensite type.

The other type of tested materials can be labelled as ledeburite weld deposits. In Fig. 6, there is clearly visible that the prevailing part of the weld metal is formed by carbides. There are primarily excluded carbides of chrome (weld deposit OK 8478) and titanium (OK 8484) in an austenite-martensite matrix. In both cases, carbides are equally distributed in weld metal. Row characteristic was not observed.

Metallographic analysis has shown a similar character of the inner structure of weld metal originating from the E-B 511 electrode to the base material of the blade disc (see Fig. 7). It is a martensite structure placed to a metal matrix of residual austenite. Metallographic sample of the blade disc was made from a middle part of the blade edge. Both of the materials form a smooth grained structure. In the weld metal E-B 511, there were observed small hollows and bubbles, which could be caused by a higher humidity of a flux electrode coating during the welding process. However, the abrasive test did not prove a higher wear of the tested material depending on a defect of the weld bead.

Wear Testing According to the Norm ČSN 01 5084

The laboratory testing of the wear on abrasive cloth is based on the norm ČSN 01 5084. A tested sample is held in a holder and pressed by a weight to an 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. Samples are cleaned and the weight decrease determined by weighing, see Tab. III.

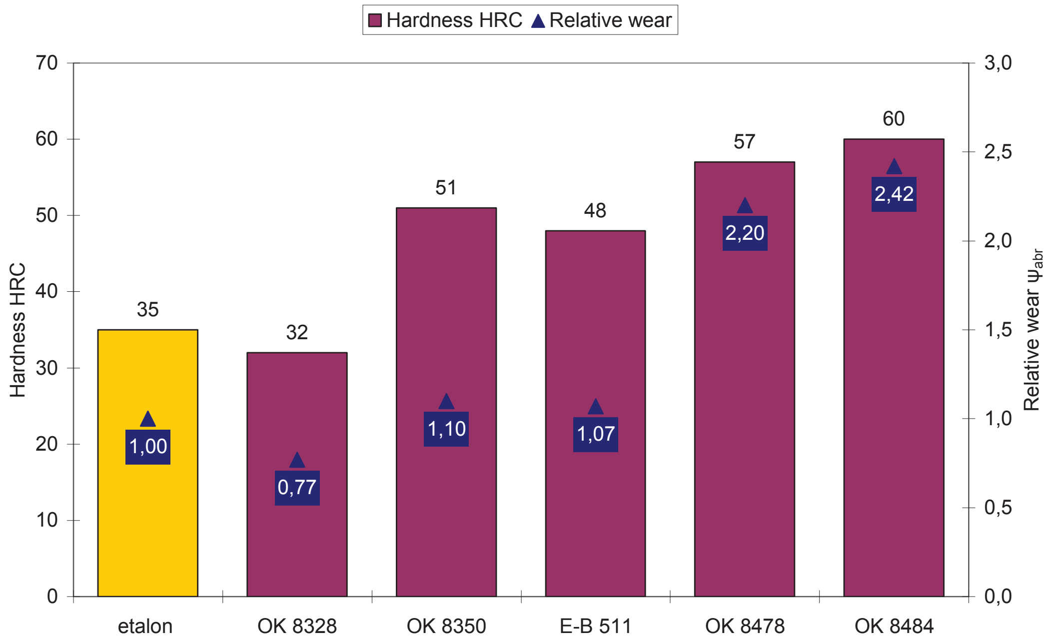
Relative wear ψ_{abr} wa3s calculated according to the following relation:

$$\text{weight} - \psi_{abr} = \frac{m_{et}}{m_{vzo}},$$

where
m_{et}..... weight loss of the etalon [g],
m_{vzo}... weight loss of the sample [g].

III: *Weight losses of tested samples*

Number of the measurement	Weight losses [mg]					
	Etalon Blade disc	OK 8328	OK 8350	E-B 511	OK 8478	OK 8484
1	187	231	172	179	84	77
2	189	249	168	174	85	79
3	185	244	170	171	86	75
Average	187.0	241.3	170.0	174.7	85.0	77.0
Standard deviation	1.63	7.59	1.63	3.30	0.82	1.63
Variation coefficient	0.87	3.14	0.96	1.89	0.96	2.12



8: *Relative resistance to abrasive wear on an abrasive cloth*

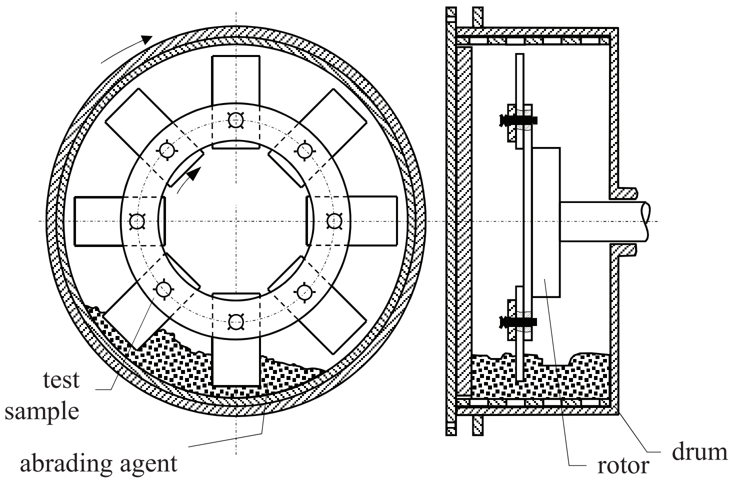
Conditions of the Laboratory Testing

The shape of the samples for testing abrasive wear on an abrasive cloth with solid particles was a cube sized 10×10×10 mm. There were three samples from each material. The comparing etalon was the original steel from the blade disc. The length of the friction course was 250 m. Total diameter of the revolving disc was 480 mm. Maximal sliding speed of the tested body did not exceed 0.5 m×s^{-1}. Specific pressure which was generated on a sample did not exceed 0.32 N×mm^{-2}. Radial motion of the tested body was 3 mm×turns^{-1}. The abrasive medium is formed according to the norm ČSN 01 5084 by corundum of granularity 120 units. This test characterizes interaction of two bodies (Gahr, 1998; Trezona *et al.*, 1999; Pošta *et al.*, 2002).

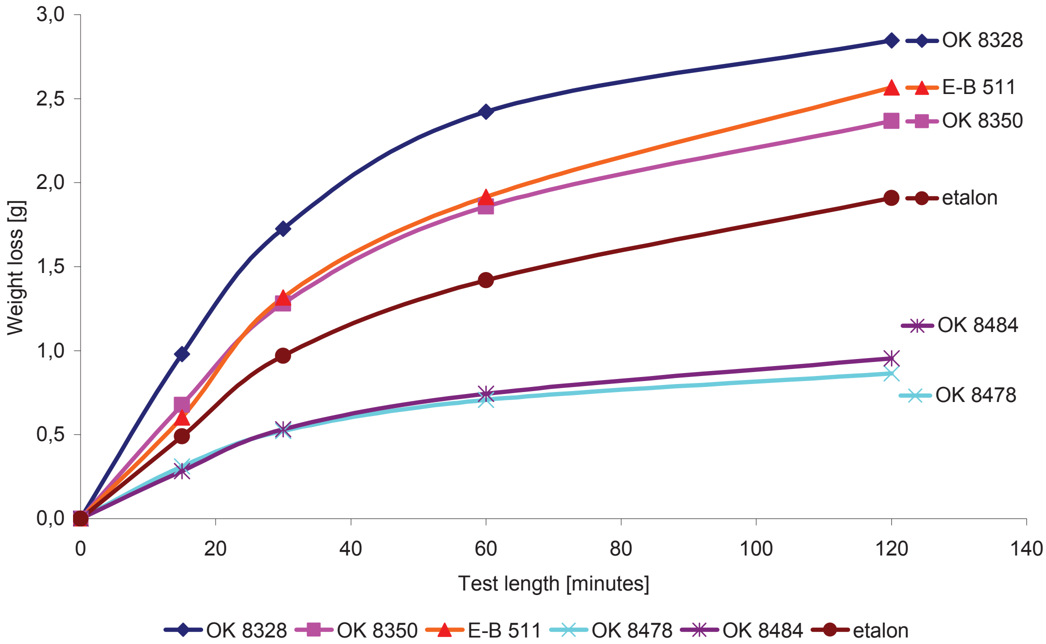
Individual samples were prepared on metallographic saw using the method of accurate cutting. Important factor when preparing samples was to guarantee optimal cooling of a sample. A good heat removal eliminates a heat affected area which could increase weight losses in the first measurement. Relative resistance to abrasive wear is recorded in Fig. 8.

Abrasive Wear on Bond's Device

In order to identify wear resistance in loose abrading agents Bond's drum device (see Fig. 9). Two, four or eight test samples are fastened on a rotor (ω_2 = 64.4 s^{-1}). The rotor is put in a testing drum which turns itself in the same direction (ω_1 = 7.3 s^{-1}). Wear extend was measured in the time interval of 15, 30, 60 and 120 minutes. After each of the interval



9: *Bond's testing device*



10: *Weight losses of tested materials in Bond's device*

there were put new abrading agents. Abrading agent was 1,000 cm³ stone fraction of granularity between 8 and 16 mm. After each time interval, each sample was cleaned carefully in order to remove remains of dirt from abrading agents. Cleaned test samples were weighted on electronic weight with the accuracy of 0.001 g.

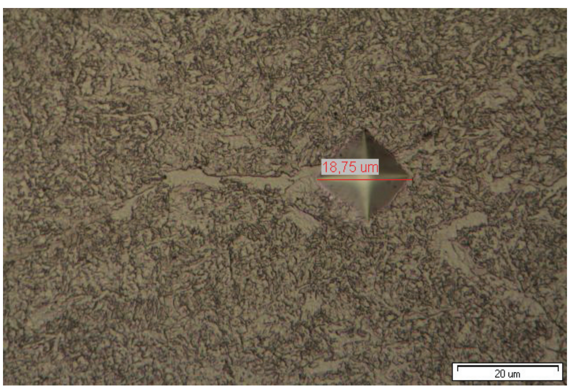
This experiment was processed because the conditions in the testing machine are very similar to real working conditions of a dissolver. Tested materials were again deposited on a base steel material class 11 373 in two layers on the whole surface. Further, samples were machined on a surface grinding machine with a minimal decrease of deposited hard metal.

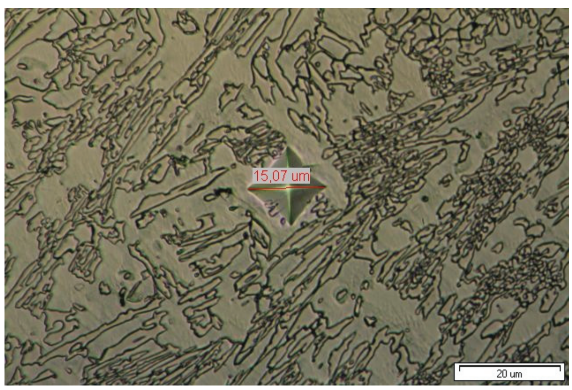
Based on results from the Bond's device with broken stone (see Fig. 10), there could be recommended a material with minimal losses for production and renovation of machine parts working with loose or liquid materials. Renovation could be also recommended for abrasively-worn mixing and granulating machines.

Microhardness of the Metal Layers Tested

Microhardness is crucially influenced by chemical composition of base material of a coated electrode. Microhardness was measured with Hanneman'smicrohardness device, which is a part of a metallographic microscope Neophot 21, according to a standard Vickers' method. A diamond-tipped cone of 136° using the force of 9.98 N is being pressed into the material. According to the length of diagonals the HV microhardness value is read.

As it is apparent from Fig. 11, the difference between the diagonals of injector imprints in ferrite-sorbite structure OK8328 and carbidic structure OK8484 is ca. 3.6 µm. As the tested structures are small grained, the microhardness measurement is introduced as a total regardless the individual





11: *An injector HV 10 imprint OK 8328 (left) OK 8484 (right)*

IV: *Microhardness of tested samples*

Tested materials	Microhardness HV 10					
	Measurement No. 1	Measurement No. 2	Measurement No. 3	Average	Standard deviation	Variation coefficient
OK 8328	297	280	273	283.33	10.08	3.56
OK 8350	655	639	661	651.67	9.29	1.42
E-B 511	699	705	672	692.00	14.35	2.07
OK 8478	856	874	865	865.00	7.35	0.85
OK 8484	902	895	916	904.33	8.73	0.97
Etalon	410	396	415	407.00	8.04	1.98

structural phases. The individual microhardness values are recorded in Tab. IV.

Material hardness is characterized as its resistance to infiltration by foreign elements to the base metal matrix. It is accordingly the main evaluation criterion of abrasive wear. (Kotus M., Gyurica Ľ, 2010; Pauliček, *et al.*, 2013)

CONCLUSION

The paper is focused on using hard metal electrodes OK 83xx, E-B 511, OK 84xx for prolonging the service life (respectively renovation) of blade disc of mixing machine "Kreis-Biogas-Dissolver". The blade disc is an active part which provides optimal immixing and homogenization of input materials used for biogas production. As edges of blade discs are subject to a substantial abrasive wear, to prolong the service life it is possible to apply hard metal weld deposit. The condition is to preserve the tenacity of the whole system.

Tested materials could be divided into two categories of weld metal: sorbite-martensite and ledeburitic weld deposit.

Based on metallographic analysis, it can be stated that base material and electrode OK 8328 were considerably mixed up. Ferrite-sorbite structure of the weld metal was not stifled even when applying more weld beads. Tested samples with this type of weld deposit have performed the lowest resistance to abrasive wear: both on an abrasive cloth and in Bond's device. Hardness values correlate with the values of microhardness of weld metal. Metallographic scratch patterns which showed no microcracks in the weld deposit area proved a good tenacity of the system.

Metallographic analysis of weld metal OK 8350 has showed microcracks in the transition are between the weld metal and base material. Even by preheating the base material according to the producer guidelines this defect was not eliminated. Generally, microcracks in the weld metal considerably lower usage of such a weld deposit. Microstructure of the weld metal and its hardness correlate with the abrasive wear according to the laboratory experiments.

Weld metal produced by the E-B 511 electrode is similar to the blade disc base material. According to the microhardness results, there can be found a smaller amount of residual austenite.

Tested materials of the type OK 84xx have preformed a perfect abrasive resistance, especially on Bond's device with broken stone. Carbidic structure of the weld metal has reached the highest hardness values. Metallographic scratch patterns have not showed any defects of the weld metal, such as hollows, cracks and slag.

To sum up the results from all processed experiments, weld deposits from OK 84xx electrodes can be recommended to environments with considerable abrasive stresses.

SUMMARY

Wear of technical materials due to abrasive and erosive stresses is one of the reasons of degradation processes of the whole machine, respectively a whole machine line. As it is a slow process, lower quality of the production process precedes an unavailability time. This aspect is shown especially in the fields of transport of loose materials, mixing equipments or active parts of soil-processing machines.

This paper analyses abrasive resistance of hard metal weld deposit electrodes designed for renovation of machine parts. All results of laboratory experiments are compared to the original material of a blade disc of a mixing machine "Kreis-Biogas-Dissolver" (etalon). In order to compare chemical composition with tested electrodes, an EDS analysis was processed. This analysis has identified accumulation of chrome carbides, which should lower a wear speed of the edge of the blade disc.

Abrasive test on an abrasive cloth has showed that electrodes OK 83xx and E-B 511 have shown the same resistance as the etalon. These results were confirmed also on the Bond's device with loose abrading agents, where the etalon had even lower weight losses than the hard metal weld deposit electrodes.

Tested materials of the type OK84xx have on the contrary shown the possibility of application to the conditions with high abrasive and erosive wear. Resistance of these materials on an abrasive cloth was ca. 2.4 times higher than the resistance of the etalon. Also the Bond's device degradation test after 120 minutes has shown by 1 g lower weight loss of these materials than the blade disc base material.
Carbide structure with a residual austenite and martensite formed by weld metal of OK84xx electrodes can be stated as optimal in the renovation processes of machine part with an excessive abrasive wear. However, the structure will not be able to resist an excessive dynamic stresses, which could result in crumbling out the weld bead.

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Contact information
Jiří Votava: jiri.votava@mendelu.cz
Vojtěch Kumbár: vojtech.kumbar@mendelu.cz