Abrasive wear of high chromium Fe-Cr-C hardfacing alloys

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Abstract: Weld deposits are one of the most used economical ways of the wear resistance increase. The study compares the characteristics of the overlay material welded-on and the abrasive wear resistance. The research has been carried out using hardfacing alloys reinforced with primary chromium carbides and complex carbides. The overlay material was deposited on the low-carbon steel S235JR using the gas metal arc welding (GMAW) method. Four different commercial overlay materials were studied in terms of the microstructure effect. The abrasion wear testing was carried out using the abrasive cloth of grit 120 according to CSN 01 5084. The microstructure characterisation and surface analysis were made using optical and scanning electron microscopy. The results illustrate a significant effect of primary carbides on the abrasive wear resistance of weld deposits.

Keywords: hardfacing alloy; abrasive wear; Pin-on-disk; carbide

Fe-Cr-C alloys are used in several conditions where extreme erosion occurs and therefore the abrasion resistance is necessary. Their exceptional abrasive and erosive wear resistance results primarily from their high volume fraction of hard carbides, though the toughness of the matrix also contributes to the wear resistance.

The investigations of Fe-Cr-C alloy microstructures have shown that these types of materials have hypoeutectic, eutectic, and hypereutectic structures. M_7C_3 primary carbides form in large amounts at higher carbon concentrations. These types of microstructures possess good wear resistance properties (Colaco & Vilar 2003; Chatterjee 2006).

This kind of hard material can be represented by high chromium white cast iron, with an extremely high hardness value of M_7C_3 (about 1600 HV). M_7C_3 is surrounded by austenite, which is relatively soft compared to M_7C_3, so a crack will spread along the interface between austenite and M_7C_3 (Chien *et al.* 2006).

High chromium content Fe-Cr-C hardfacing alloys can also be used commercially for such components that are designed to endure harsh abrasive conditions. The massive carbides present in the microstructure are $M_{23}C_6$. These can be described as composites with large and hard carbides in a softer body centered cubic Cr-Fe alloy matrix.

If high chromium content (Fe-Cr-C) hardfacing alloys are in hypereutectic, i. e. primary $M_{23}C_6$ is surrounded by the Cr-Fe and $M_{23}C_6$ eutectic structure, they will reduce the occurrence of the crack, because the lamellar eutectic structure will resist crack spreading along the grain boundary (Gulenc & Kahraman 2003; Chien *et al.* 2006).

Hardfacing is a commonly employed method to improve the surface properties of agricultural tools, the components for mining operation, soil cultivation equipments, and others. An alloy is homogenously deposited onto the surface of a soft material (usually low or medium carbon steels) by welding, with the purpose of increasing the hardness and wear resistance without any significant loss in

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Table 1. Chemical composition of electrodes (in weight percentages)

	C	Si	Mn	Cr	Mo	V	Ni	W	Nb
Hardfacing 1	3.2	1.0	1.0	29.0	0.7	0.2	0.35	×	×
Hardfacing 2	3.5	1.0	0.2	35.0	×	0.2	0.15	×	×
Hardfacing 3	4.4	1.2	0.3	23.5	6.5	1.5	×	2.2	5.5
Hardfacing 4	4.5	0.5	0.5	17.5	1.0	1.0	×	1.0	5.0

Table 2. Welding conditions

Electrode diameter	1.6
Arc voltage	27
Welding current	250
Electrode polarity	positive
Welding speed (cm/min)	13
Preheating	no
Deposition rate (kg/h)	14.3

ductility and toughness of the substrate (Eroglu & Ozdemir 2002).

A wide variety of hardfacing alloys are commercially available for the protection against wear. Deposits with a microstructure composed by dispersed carbides in austenite matrix are extensively used for abrasion applications and are typically classified according to the expected hardness. Nevertheless, the abrasion resistance of a hardfacing alloy depends on many other factors such as the type, shape, and distribution of hard phases, as well as the toughness and strain hardening behaviour of the matrix. Chromium-rich electrodes are widely used due to their low cost and availability, however, more expensive tungsten or vanadium-rich alloys offer, a better performance due to a good combination of hardness and toughness. Complex carbides electrodes are also used, especially when the abrasive wear is accompanied by other wear mechanisms (Kim *et al.* 2003).

The technology of surfacing comprises oxyacetylene gas welding (OAW), gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG), submerged arc welding (SAW), plasma transferred arc welding (PTA), gas metal arc welding (GMAW) (Gregory 1980).

EXPERIMENTAL PROCEDURES

Material characterisation

The substrate material used was steel CSN EN S235JR with the dimensions of 200 × 100 × 20 mm. The commercial hardfacing and buffer consumables, in the form of solid wire coated electrodes, were used as per the directions of the electrode and automation welder manufacturers.

Welding conditions

Hardfacing electrodes (Table 1) were deposited on the plate without preheat in the horizontal position using gas metal arc welding method. On completion of the weld deposits, each test piece was cooled down in air. The welding conditions of the electrodes are presented in Table 2.

Chemical composition, metallography, and hardness test

The chemical composition (Table 3) was determined on the overlay surface of the respective specimen using GDOES (Vnouček 2001). The hardfacing deposited plates were sectioned using the high speed SiC cutter with cooling for the specimens for chemical analysis, metallography (25 × 10 × 20 mm), and for the wear test specimens (25 × 25 × 25 mm).

Metallography test specimens were then ground successively using the belt grinder and emery papers

Table 3. Chemical composition of the measured object shown in Figure 3

Place	C	Si	Mo	V	Cr	Mn	Fe	W	Nb
1	34.11	0.08	0.5	1.61	26.99	0	33.82	0.69	1.97
2	30.66	0.05	0.54	1.69	28.51	0	35.74	0.64	1.25
3	36.56	0.05	5.50	1.28	1.47	0.08	1.73	0.77	52.51
4	1.26	0.62	0.38	0.30	6.65	0.53	89.11	0.69	0.46

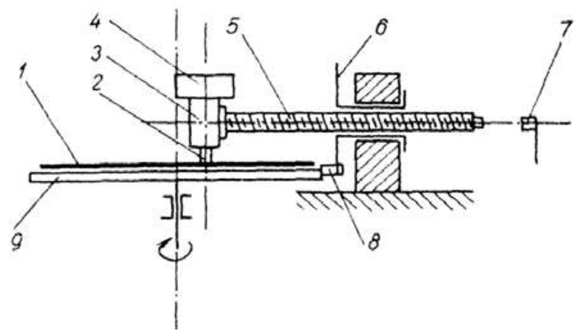

Figure 1. Diagrammatic representation of the pin-on-disk testing machine: 1 – abrasive cloth, 2 – specimen, 3 – holder, 4 – weight, 5 – screw, 6 – nut with cogs, 7 – limit switch, 8 – pin, 9 – horizontal plate

and finally polished with Al_2O_3 powder, cleaned with acetone and dried. The polished specimens were etched with Kalling´s or Vilella-Bain`s reagent and their microstructure was observed using an optical microscope.

Abrasive wear test

Before the abrasive wear test, all specimens were cleaned with acetone and then weighed on a mechanical balance (type PRL TA 14) with an accuracy of ± 0.05 mg. The laboratory tests of the relative wear resistance were carried out using the pin-on-disk machine with the abrasive cloth according to ČSN 5084. The pin-on-disk machines are used most often, the simplicity and reliability being their advantages. The results variance is relatively small. The variable quality of the abrasive cloth must be continuously compensated by the use of etalons. The pin-on-disk testing machine (Figure 1) consists of the uniform rotating disk whereon the abrasive cloth is fixed. The tested specimen is fixed in the holder and pressed against the abrasive cloth by the weight of 2.35 kg. The screw makes possible the radial feed of the specimen. The limit switch stops the test. During the test, the specimen moves from the outer edge to the centre of the abrasive cloth and a part of the specimen comes into contact with the unused abrasive cloth.

$$\text{wear ratio} = \frac{\text{weight loss of the deposit}}{\text{trace of specimen on disc (41.5 m)}}$$

RESULTS AND DISCUSSION

Microstructure

The typical microstructures of the hardfacing alloys studied are shown in Figure 2. The first and second layers of Cr-rich deposits are of an eutectic matrix with proeutectic M_7C_3 -type chromium carbides (1500 $HV_{0.1}$ microhardness). In the second layer, both the volume fraction and the mean size of chromium carbides are higher than in the first one. The volume fraction of chromium carbides in the second layer, as calculated from the picture analysis, was 41.5%.

The first layer of the complex carbides deposit is mainly eutectic with finely dispersed niobium hard particles, while the second deposit layer is of a similar microstructure which includes hypereutectic chromium-rich M_7C_3 (26% in hardfacing 3 and 19% in hardfacing 4) and niobium-rich MC carbides (3% in hardfacing 3 and 4) (Figure 3).

Figure 3 shows EDX composition of the deposit with the identification of phases (electrode 4 second layer). Table 4 presents the chemical composition of the measured object in the second layer electrode 4.

Table 4. Chemical composition of the layers

	C	Si	Mn	Cr	Mo	V	Ni	W	Nb	Fe
First layer										
Hardfacing 1	2.93	1.06	1.01	30.33	0.60	0.19	0.30	×	×	bal.
Hardfacing 2	2.04	0.76	0.13	26.31	×	0.10	0.12	×	×	bal
Hardfacing 3	4.07	1.08	0.21	19.00	4.44	1.35	×	0.75	4.64	bal
Hardfacing 4	3.46	0.37	0.52	12.19	0.54	0.63	×	0.38	2.40	bal
Second layer										
Hardfacing 1	3.03	1.07	1.03	32.37	0.64	0.20	0.35	×	×	bal
Hardfacing 2	2.93	0.80	0.15	31.16	×	0.18	0.12	×	×	bal
Hardfacing 3	4.43	1.16	0.28	21.70	4.65	1.52	×	1.52	5.43	bal
Hardfacing 4	4.96	0.49	0.49	16.53	0.66	0.81	×	0.53	7.65	bal

bal – balance

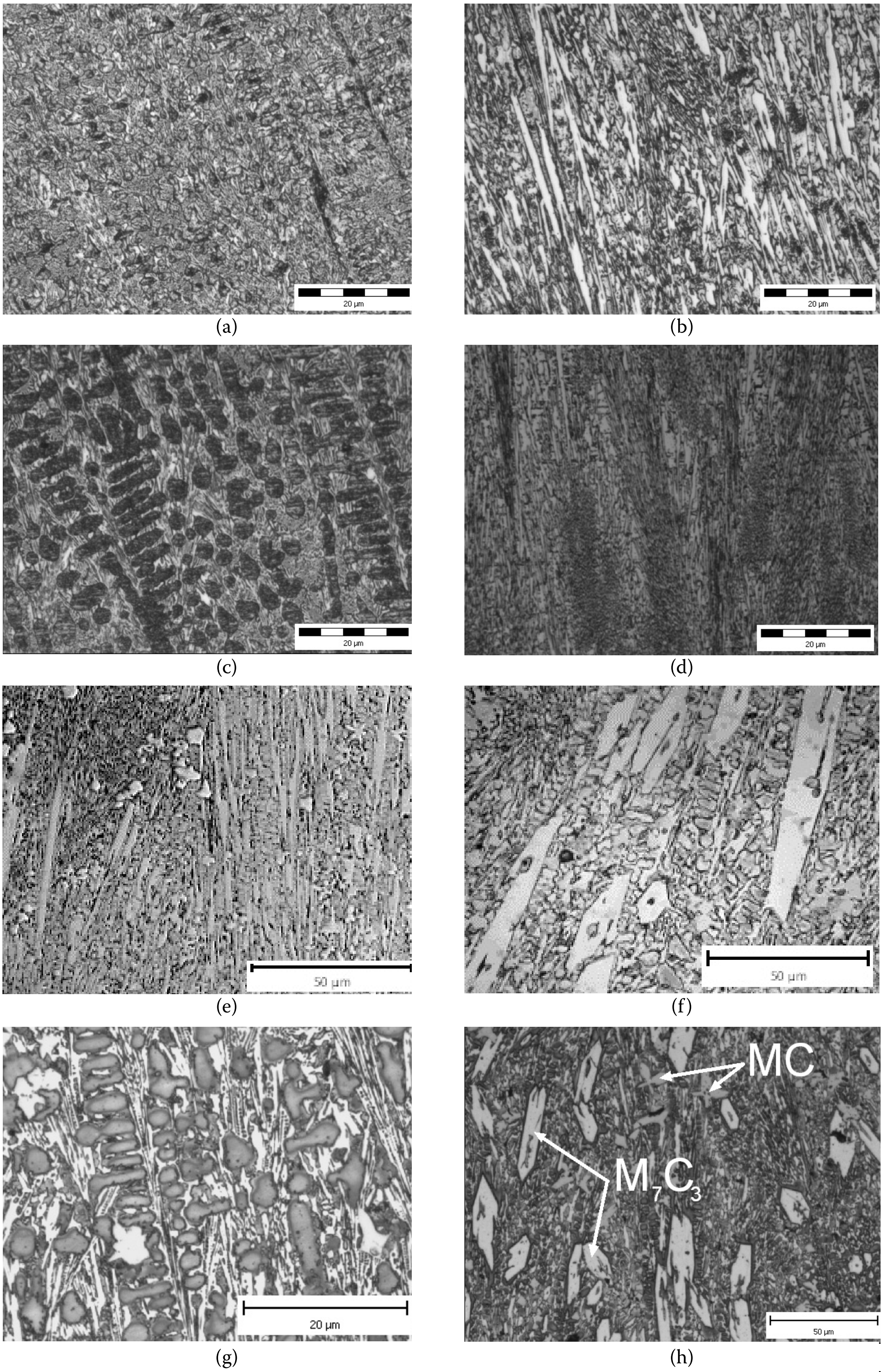

Figure 2. Hardfacing microstructures: (a) Cr-rich, electrode 1, first layer, (b) Cr-rich, electrode 1, second layer, (c) Cr-rich, electrode 2, first layer, (d) Cr-rich, electrode 2, second layer, (e) complex carbides, electrode 3, first layer, (f) complex carbides, electrode 3, second layer, (g) complex carbides, electrode 4, first layer, (h) complex carbides, electrode 4, second layer; images were made using an optical microscope

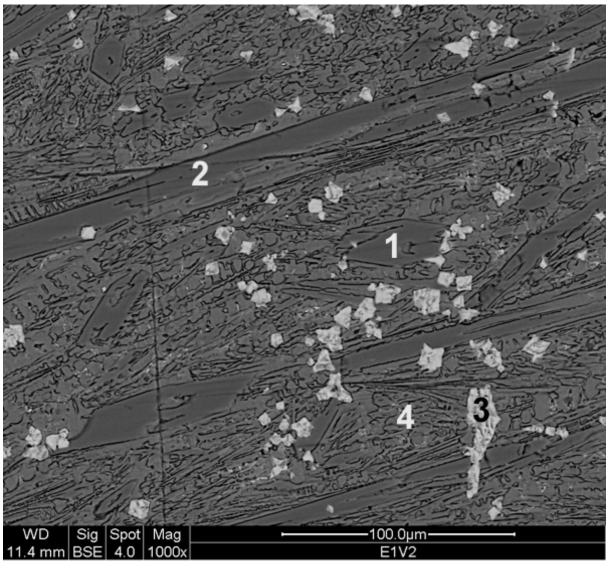

Figure 3. Structure of the overlay (Electrode 4) determined by SEM (BSE) method

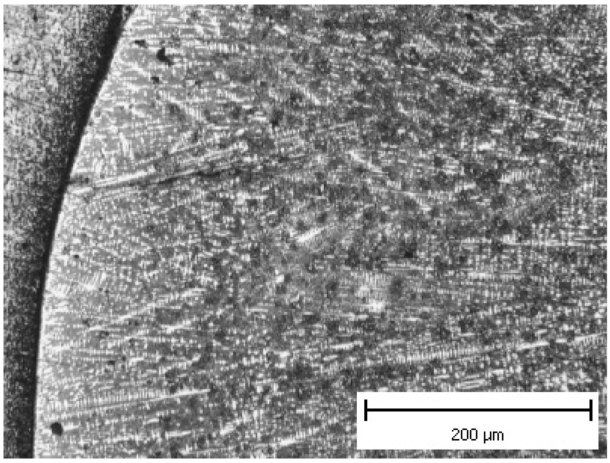

Figure 4. Preferential orientation of chromium carbides near the interface between the first welded-on layer and the substrate

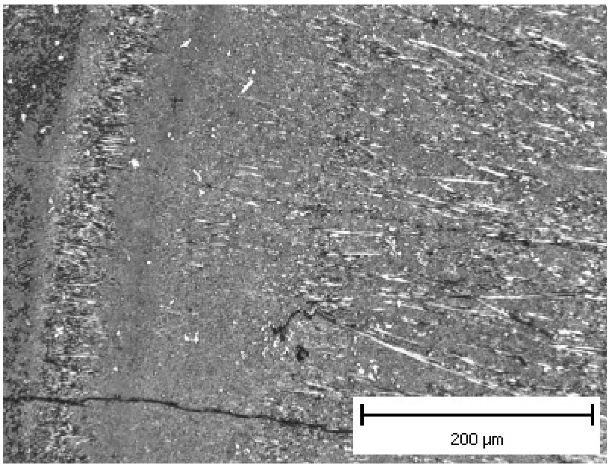

Figure 5. Distribution of chromium carbides in the second layer of hardfacing 4

Abrasive wear resistance

Table 5 presents the general results of the weight loss from the pin-on-disk test. The best abrasion resistance was obtained in the second layer of the complex carbides deposit, in which the elevated volume fraction of the coarse M_7C_3 carbides provided a barrier against indentation, grooving, and cutting. This beneficial effect is probably reinforced by the NbC particles. The worn surface shows that MC carbides were brittle fractured.

Another important factors in the abrasion resistance are the carbides orientation and the size of particles (Dogan & Hawk 1995). Carbides in the second layer of Cr-rich and complex carbides hardfacing are not of especial orientation (Figure 4), while the first layer of both deposits showed carbides elongated in the direction normal to the interface between the hardfacing and the substrate (Figure 5). The carbide size is presented in Table 6 and the cumulative frequency curve is presented in Figure 6.

Relation between hardness and abrasion resistance of the deposits

The average hardness of the hardfacing alloys is shown in Table 7. The lowest values were obtained in specimens with eutectic microstructures, such as the first layer of the complex carbides and Cr-rich

Table 5. Weight loss and wear rate of the used hardfacing

	Hardfacing 1	Hardfacing 2	Hardfacing 3	Hardfacing 4
One-layer				
Weight loss (mg)	117.205	158.712	22.134	69.036
Wear rate (mg/m)	2.824	3.824	0.534	1.664
Two-layer (second layer)				
Weight loss (mg)	115.106	130.405	20.431	43.918
Wear rate (mg/m)	2.774	3.133	0.492	1.058

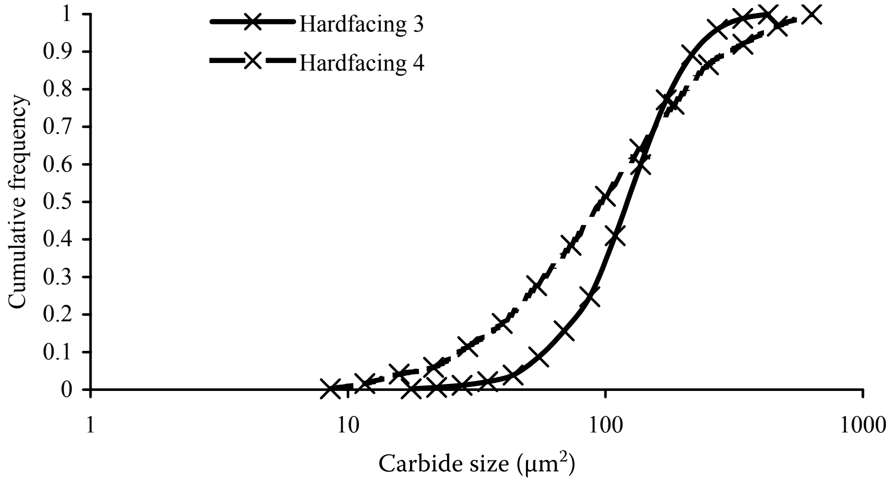

Figure 6. Cumulative frequency of the M_7C_3 carbide size in the second layer of hardfacings 3 and 4

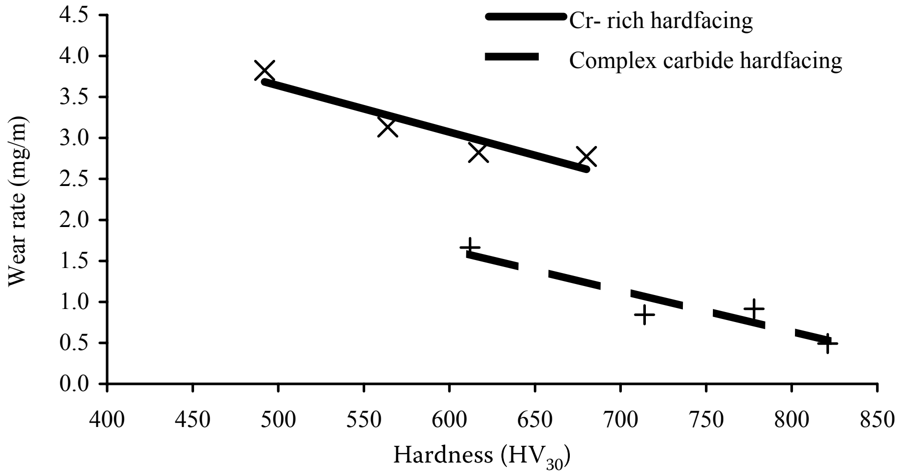

Figure 7. Relation between hardness and the abrasion wear rate of the tested hardfacing alloys

deposits. The second layer of the complex carbides hardfacing showed the highest hardness. Figure 7 presents the relation between the wear rate and hardness of hardfacing materials. The results are shown separately for the deposits of eutectic structure and of eutectic structure with primary carbides M_7C_3 and MC or MC only.

Table 6. Mean carbide size (μm^2) in the second layer of hardfacings 3 and 4

Type of carbide	Hardfacing 3	Hardfacing 4
MC	66	64
M_7C_3	124	94

CONCLUSION

Two-layer complex carbide deposits showed the best abrasive wear resistance of all the tested hardfacing alloys.

In the studied hardfacing materials, the M_7C_3 carbides are of the decisive influence on the abrasive wear resistance. These carbides are an effective barrier against the abrasive particle advance.

Microcutting by abrasive particles was the dominant mechanism of wear. Plastic deformation,

Table 7. Hardness HV_{30} of deposits made using various electrodes

	Hardfacing 1	Hardfacing 2	Hardfacing 3	Hardfacing 4
One-layer				
Hardness	617	492	714	612
Two-layer (second layer)				
Hardness	680	564	812	778

ploughing, was determined on the deposits of eutectic structure.

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Abstrakt

Chotěborský R., Hrabě P., Müller M., Savková J., Jirka M. (2008): **Abrazívní opotřebení vysokochrómových Fe-Cr-C návarů**. Res. Agr. Eng., **54**: 192–198.

Návarové vrstvy jsou jednou z nejvíce užívaných ekonomických cest ke zvýšení odolnosti proti opotřebení. Studium porovnává mikrostrukturní charakteristiky návarových materiálů a odolnost vůči abrazívnímu opotřebení. Studium bylo prováděno na návarových materiálech, kde ve struktuře byly primární chrómové karbidy a karbidy komplexní. Návarový materiál byl nanesen na nízkouhlíkovou ocel S235JR metodou odtavující se elektrody v ochranné atmosféře. Čtyři různé komerční návarové materiály byly studovány z hlediska efektu mikrostruktury. Test abrazívního opotřebení byl prováděn na brusném plátně zrnitosti 120 dle ČSN 015084. Charakteristika mikrostruktury a analýza povrchu byla prováděna postupy optické a elektronové mikroskopie. Výsledky ukazují významný vliv primárních karbidů na odolnost návarů vůči abrazívnímu opotřebení.

Klíčová slova: návarový materiál; abrazívní opotřebení; Pin-on-disk; karbidy

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