THE EFFECT OF MICROSTRUCTURE OF THE HYPOEUTECTIC FE-CR-C HARDFACING ON ABRASIVE WEAR*

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Hardfacing is one of the most useful and economical ways to improve the performance of component subjected to severe wear conditions. A study was made to compare the microstructure and hardness and abrasion resistance of hardfacing alloys reinforced with chromium carbides eutectic. The hardfacing alloy was deposited onto S235JR low carbon steel plates by a flux cored arc welding method. The commercial hardfacing electrode was employed to investigate the effect of the microstructure on mechanical properties as hardness and abrasive wear. Microstructure characterizations were made using optical microscopy. The abrasion tests were carried out in a rubber abrasion machine. The value of the abrasion resistance and the value of the hardness showed dependencies on ratio of eutectic in the hardfacing matrix.

hardfacing alloy; abrasion wear; microstructure; weld deposit

INTRODUCTION

Hardfacing is a commonly employed method to improve surface properties of agricultural tools, component for mining operation, soil preparation equipments and others (Richardson, 1967; Karoonboonyanan et al., 2007; Horvat et al., 2008). Alloy with higher hardness is deposited onto the surface of a soft material (usually low or medium carbon steel) by welding. Technology of surfacing is used as 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; Lancaster, 1993).

Fe-Cr-C alloys are used in several conditions where there is extreme erosion and therefore, high abrasion wear resistance is required. 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 (Buchely et al., 2005; Suchánek et al., 2007; Chotěborský, 2008).

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 are formed in large amounts at higher carbon concentrations. These types of microstructures are of good wear resistance properties (Colaco, Vilar, 2003; Chatterjee, 2006).

This group of materials can be represented by high chromium white cast iron, containing high portion of very hard M_7C_3-carbides (1350–1600 HV) (Gundlach, Parks, 1978; Berns, 2003; Buytoz, 2006; Suchánek et al., 2007). M_7C_3 is surrounded by austenite, which is relatively soft compared to M_7C_3. Cracks also develop along the interface between austenite and M_7C_3 (Atamert, 1990).

Several studies (Gulenc, Kahraman, 2003; Buchely et al., 2005; Bhakat et al., 2007; Chotěborský et al., 2009) have been focused on evaluation of abrasive wear of different hardfacing alloys. Influence of general microstructure on abrasive wear, toughness and other mechanical properties was observed. However, only limited numbers of studies have been devoted on evaluation of ratio phases and their influence on mechanical properties. For example Polak et al., (2009) described the influence of carbide area and inter-particle distance between carbides on abrasive wear resistance in multiphase matrix-carbide materials. He found out that the abrasive wear resistance increased with increased content of carbides and decreased with higher inter-particle distance between carbides in multiphase matrix-carbide materials.

This study was focused on evaluation of ratio phases in Cr-rich commercial hardfacing and influence of ratio

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phases on mechanical properties such as hardness and abrasive wear resistance.

MATERIALS AND METHODS

The commercial hardfacing electrode was applied onto S235JR steel plates. The nominal chemical composition of S235JR steel and electrode (OK Tubrodur 14.70) is shown in Table 1 and Table 2, respectively.

The deposition was carried out in flat position using ESAB Mini 2A welding machine; the welding process parameters with constant welding speed 20 cm min^{-1} for electrode are shown in Table 2. After deposition, the samples were cooled in air. Fig. 1 shows the location of the different welding layers. Selected sample with uniform structure was tested as shown in Fig. 1. Dimension of the samples were 25 mm × 25 mm × 20 mm (Brožek, Nováková, 1991).

The hardness of the hardfacing deposits was measured by the Vickers method using a load of 294 N (HV 30) HV$_{30}$ method with a 294 N repeated eleven times per sample. Optical microscopy (Zeiss Jenavert) was used to analyze the microstructure of the specimens. Eleven pictures of microstructure of the same hardfacing layer were used for the picture analysis using the software QuickPhoto Industrial 2.2. Surface was grinded, polished and etched with picric acid (2% solution) before analyzing. The hardness of the matrix phases was measured by the Vickers method for microhardness using a load of 0.49 N (HV 0.05) also repeated eleven times per sample.

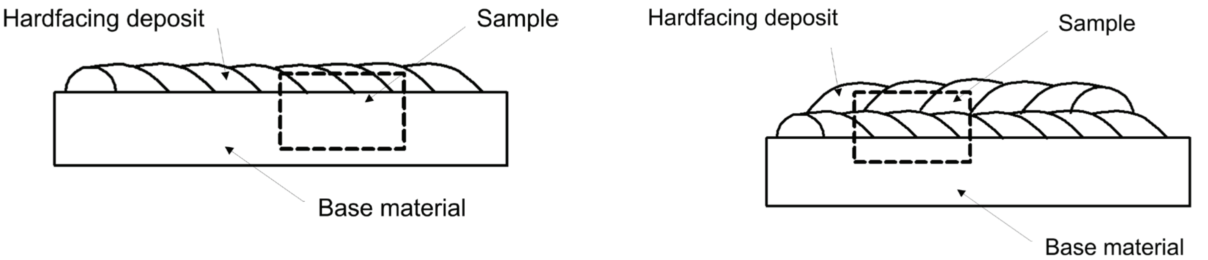
Abrasive wear test (five times per samples) was carried out in a rubber testing machine (Fig. 2) using corundum particle F120 (Fig. 3) (Brožek et al., 2009). The normal load was 2.23 kg, wear distance was 600 m. Before testing, all specimens were cleaned in ultrasonic bath and rinsed with warm air. The abrasive wear resistance was determined from the volume loss results, which was measured with 0.01 mg resolution (WA 35 type PRL T A14). For the etalon, sample made of steel 27CrMnB5 (0.002% B, 0.27% C, QT steel,

Table 1. Chemical composition of base material (weight percentage)

C	Mn	S	P	Fe
0.074	0.33	0.006	0.0025	rest

Table 2. Chemical composition of electrode (weight percentage)

C	Cr	Mo	V	Si	Mn	Fe
3.5	22	3.5	0.4	0.4	0.9	rest



(a) (b)

Fig. 1. Selected sample of one overlay (a) and two overlay (b) for test

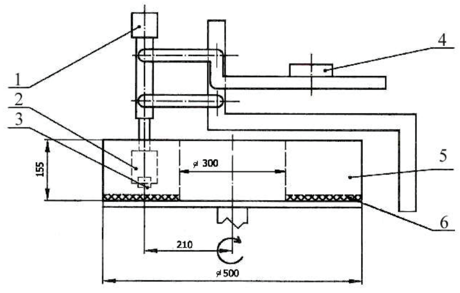


Fig. 2. Scheme of abrasive wear tester, 1 – load; 2 – clamping head; 3 – sample; 4 – counterweight; 5 – rotating container; 6 – rubber (60 ShA)

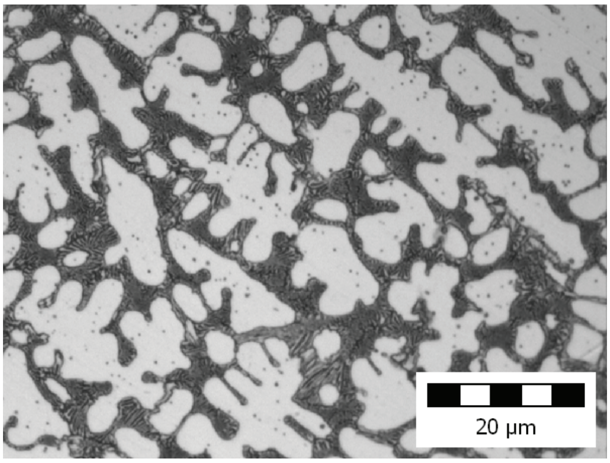


Fig. 3. Microstructure of hardfacing layer (first layer, weld deposit parameters – U = 30 V, I = 200 A), light – austenite; dark – eutectic

EN 10083-2, producer – RUUKKI) with martensitic structure that was heat treated on hardness 537 ± 10.4 HV was used. This steel is usually used for agriculture tool such as chisels, plough and other. The wear resistance was determined using equation (1).

$$\Psi = \frac{V_e}{V_m} \ [1] \qquad (1)$$

where V_m is the volume loss of tested material and V_e is the volume loss of etalon. The volume loss was determined from mass loss using equation (2).

$$V = \frac{m}{\rho} \ [m^3] \qquad (2)$$

where m is the mass loss of material and ρ is the density of tested material. Density of hardfacing layer was 7 550 ± 15 kg.m^{-3} and density of 27CrMnB5 was 7 850 ± 20 kg.m^{-3}, were determined according to hydrostatic method (Kittel, 1985).

Ratio of hardness (R_H) was determined using equation (3).

$$R_H = \frac{H_m}{H_e} \ [1] \qquad (3)$$

where H_m is the hardness of hardfacing layer and H_e is the hardness of etalon.

The measured amounts of hardness and abrasive wear were evaluated using linear method with computer program Statistica (Statsoft, 2008).

RESULTS AND DISCUSSION

The typical microstructure of hardfacing is shown in Figs. 3, 4 and 5. The first layer of Cr-rich deposit has a hypoeutectic matrix. This matrix consisted of austenite and eutectic (Fig.3). The hypoeutectic specimens were microhardness of austenite 640 ± 40 HV$_{0.05}$ and microhardness of eutectic 1020 ± 65 HV$_{0.05}$. The second layer of Cr-rich deposit has a hypoeutectic (Fig. 4) or eutectic matrix (Fig. 5). The matrix consisted of austenite and eutectic and/or eutectic separately. The microhardness of the matrix phases had the same values as in first layer. The ratio of austenite and eutectic and their dependencies on welding process parameters is shown in Table 3. It was found that austenitic dendrites depend on welding parameters. At low voltage applied for the hardfacing, the austenitic dendrites became finer than by high setting welding voltage. This result was similar as had been described by (Polak, 2009) for multiphase matrix-carbide materials. Based on obtained results it seems that finely austenitic dendrites have higher hardness and abrasive wear resistance and detail study is necessary for more reliable information.

Table 3 presents the general volume loss and wear resistance from rubber testing machine tests for samples. Table 4 shows equations of dependence hardness and wear on ratio of eutectic. Results showed that the structure with higher eutectic volume fraction had

Table 3. Process parameters for hardfacing deposition and measured value ration of eutectic, hardness and abrasive wear

Sample number	Voltage (V)	Arc current (A)	Ratio of eutectic (%)	SD (%)	Hardness (HV)	SD (HV)	Abrasive wear (mm^3)	SD (mm^3)
First layer								
1	30	200	43.12	2.52	522	45.37	5.68	1.22
2	30	300	47.32	2.58	504	47.46	6.68	1.66
3	30	400	50.18	1.35	495	56.64	6.26	0.33
4	33	200	57.22	1.13	526	41.02	4.54	0.64
5	33	300	50.12	2.18	515	23.27	4.99	1.33
6	33	400	42.08	1.92	489	27.67	6.47	1.61
7	36	200	58.98	1.34	514	37.59	5.7	1.25
8	36	300	65.24	1.94	542	33.57	4.38	0.63
9	36	400	40.73	2.36	502	57.73	5.33	0.38
Second layer (the first layer was deposited with 33 V and 200 A)								
1	30	200	86.19	2.42	575	45.30	3.84	0.86
2	30	300	83.23	1.98	552	30.76	3.96	1.03
3	30	400	71.40	1.89	536	32.56	4.52	0.56
4	33	200	92.39	1.62	574	32.15	3.71	0.25
5	33	300	81.68	2.33	594	14.84	4.12	0.19
6	33	400	78.33	2.56	573	29.43	4.85	1.14
7	36	200	100.00	0.00	575	16.12	4.0	0.61
8	36	300	97.00	0.90	593	25.03	3.85	0.61
9	36	400	86.41	1.21	599	19.24	4.23	0.65
Etalon	quenched (900°C) and tempered (185°C)				537	10.4	14.51	0.46

SD – Standard Deviation

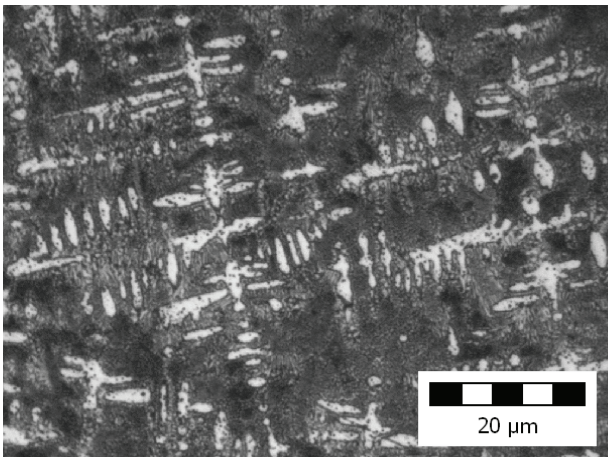


Fig. 4. Microstructure of hardening layer (second layer, weld deposit parameters – U = 30 V, I = 200 A), light – austenite; dark – eutectic

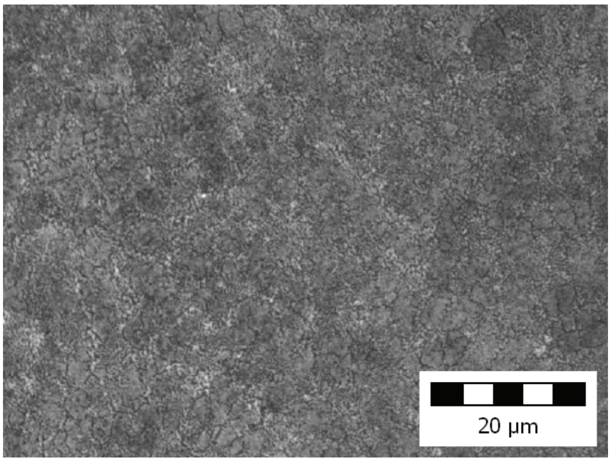


Fig. 5. Microstructure of hardening layer (second layer, weld deposit parameters – U = 36 V, I = 200 A), only eutectic

Table 4. Equation describing the relationship between hardness and wear resistance on ratio of eutectic and their statistical value

	Equation	F	P	*R*	R^2
Hardness	$HV = 429 + 1.67 \times Eu$	83.3	< 0.001	0.91	0.84
Wear	$\psi = 5.75 - 0.031 \times Eu$	42.5	< 0.001	0.85	0.73

Statistical significance of model was checked by an F-test of the overall fit, followed by t-tests of individual parameter. *R* is correlation coefficient and R^2 is coefficient of determination

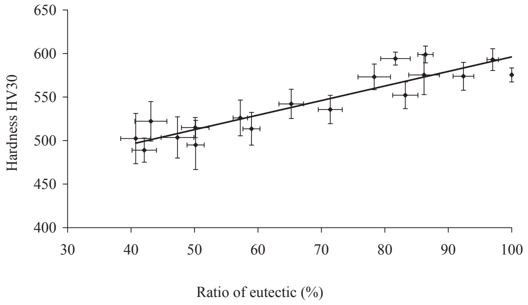


Fig. 6. Dependence between ratio of eutectic and hardness

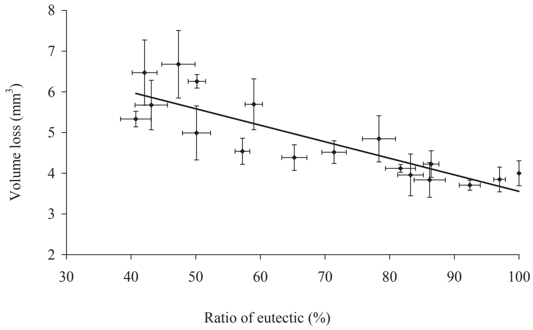


Fig. 7. Dependence between ratio of eutectic and volume loss

higher hardness (Fig. 6). Microhardness of phases was practically independent on ratio of phases. The results from the study showed that weld deposit parameters have direct effect on ratio of phases. Increased welding voltage induced an increase of the eutectic structural constituent amount in the first and second layer. Increased arc current induced a decrease of the eutectic structural constituent amount in the second layer but this welding parameter probably was not influenced by the eutectic amount in the first layer. Fig. 7 presents the dependence of the volume loss on ratio of eutectic. Results showed that the structure with higher eutectic volume fraction had higher wear resistance.

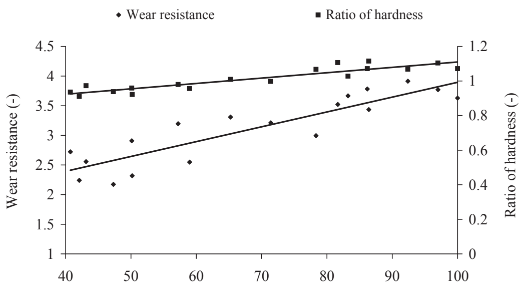


Fig. 8. Dependence between ratio of eutectic and volume wear resistance and ratio of hardness (etalon was 27CrMnB5)

Fig. 8 presents dependencies between ratio of eutectic and volume wear resistance hardfacing. Commercial heat treated medium carbon steel 27CrMnB5 was used as an etalon test. The results showed that wear resistance was practically independent on hardness. If hardness of hardfacing and steel is the same, the wear resistance of the hardfacing is higher than wear resistance of the steel. This fact is different from microstructure hardfacing and heat treated steel. Hardness phase (eutectic) in the hardfacing contributed to higher wear resistance than hardness of tempered martensite.

CONCLUSION

The results from the study revealed that the mechanical properties like hardness and abrasive wear resistance of Cr-rich hardfacing depends on volume fraction of the eutectic constituent in the matrix. The welding parameters influenced ratio eutectic in the hardfacing matrix. The different weld deposit parameters achieved different ratio of eutectic in the matrix and different size of austenite dendrite in the matrix. Increased ratio of eutectic in the hardfacing matrix resulted in increased hardness and wear resistance of the hardfacing layer. The Cr-rich hardfacing showed higher wear resistance than commercial heat treated medium carbon steel of equal hardness. The results obtained could be useful for the design of agricultural tools which would have longer life time.

REFERENCES

ATAMERT, S. – BHADESHIA, H.K.D.H.: Microstructure and stability of Fe-Cr-C hardfacing alloys. Material Science and Engineering A-Structural Materials Properties Microstructure and Processing, *130*, 1990: 101–111.

BERNS, H.: Comparison of wear resistant MMC and white cast iron. Wear, *254*, 2003: 47–54.

BHAKAT, A.K. – MISHRA, A.K. – MISHRA, N.S.: Characterization of wear and metallurgical properties for development of agricultural grade steel suitable in specific soil conditions. Wear, *263*, 2007: 228–233.

BROŽEK, M. – NOVÁKOVÁ, A. – JIRKA, M.: Device for determining material resistance to wear off with unbound particles. Written: 11. 05. 2009. Document No. 19616, Industrial Property Office. Document group UM. (in Czech)

BROŽEK, M. – NOVÁKOVÁ, A.: Comparison of resistance to abrasive wear of selected filler materials. Research in Agriculture Engineering, *37*, 1991: 31–37.

BUCHELY, M.F. – Gutierrez, J.C. – Leon, L.M. – TORO, A.: The effect of microstructure on abrasive wear of hardfacing alloys. Wear, *259*, 2005: 52–61.

BUYTOZ, S.: Microstructural properties of M7C3 eutectic carbides in a Fe-Cr-C alloy. Materials Letters, *60*, 2006: 605–608.

COLACO, R. – VILAR, R.: A model for the abrasive wear of metallic matrix particle-reinforced materials. Wear, *254*, 2003: 625–634.

GREGORY, E.N.: Surfacing by welding. Welding Institute Research Bulletin, *21*, 1980: 9–13.

GUNDLACH, R.B. – PARKS, J.L.: Influence of abrasive hardness on the wear resistance of high chromium irons. Wear, *46*, 1978: 97–108.

GULENC, B. – KAHRAMAN, N.: Wear behaviour of bulldozer rollers welded using a submerged arc welding process. Materials & Design, *24*, 2003: 537–542.

HORVAT, Z. – FILIPOVIC, D. – KOSUTIC, S. – EMERT, R.: Reduction of mouldboard plough share wear by a combination technique of hardfacing. Tribology International, *41*, 2008: 778–782.

CHATTERJEE, S.: Weld procedural effect on the performance of iron based hardfacing deposits on cast iron substrate. Journal of Materials Processing Technology, *173*, 2006: 61–69.

CHOTĚBORSKÝ, R. – HRABĚ, P. – MÜLLER, M. – SAVKOVÁ, J. – JIRKA, M.: Abrasive wear of high chromium Fe-Cr-C hardfacing alloys. Research in Agricultural Engineering, *54*, 2008: 192–198.

CHOTĚBORSKÝ, R. – HRABĚ, P. – MÜLLER, M. – SAVKOVÁ, J. – JIRKA, M. – NAVRÁTILOVÁ, M.: Effect of abrasive particle size on abrasive wear of hardfacing alloys. Research in Agricultural Engineering, *55*, 2009: 101–113.

KAROONBOONYANAN, S. – SALOKHE, W.M. – NIRANATLUMPONG, P.: Wear resistance of thermally sprayed rotary tiller blades. Wear, *263*, 2007: 604–608.

KITTEL, CH.: Introduction to Solid State Physics, 1st ed. Prague, Czech Republic, Academia 1985. (in Czech)

LANCASTER, J.F.: Metallurgy of Welding. 6th ed. London, United Kingdom, Chapman & Hall, 1993.

POLAK, R. – ILO, S. – BADISCH, E.: Relation between interparticle distance (L_{IPD}) and abrasion in multiphase matrix-carbide materials. Tribology Letters, *33*, 2009: 29–35.

RICHARDSON, R.C.D.: The wear of metallic materials by soil – practical phenomena. Journal of Agricultural Engineering Research, *12*, 1967: 22–39.

SUCHÁNEK, J. – KUKLÍK, V. – ZDRAVECKÁ, E.: Abrasive wear of materials. Prague, Czech Republic, Czech Technical University in Prague, 2007. (in Czech)

STATSOFT CR s r.o. (2008). STATISTICA (software system for data analysis), version 8.0., www.statsoft.cz

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Vliv mikrostruktury podeutektických návarů Fe-Cr-C na abrazívní opotřebení

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Navařování je jednou z často využívaných ekonomických cest vedoucí ke zvýšení otěruvzdornosti nástrojů či strojních částí. Práce je zaměřena na vliv mikrostruktury, tvrdosti a abrazívního opotřebení návaru s eutektikem tvořeného chrómovým karbidem. Návar byl nanesen na nízkouhlíkovou ocel S235JR použitím plněné trubičkové návarové elektrody. Navařování probíhalo při různých parametrech navařování s vytvořením jednovrstvého a dvouvrstvého návaru. Takto byly získány vzorky s různým podílem fází ve struktuře. Mikrostruktura byla hodnocena optickou metalografií a byl zjištěn vliv podílu fází na tvrdost návaru. Zkouška opotřebení byla provedena na přístroji s pryžovou deskou. Výsledky ukazují významný vliv mikrostruktury na odolnost proti abrazívnímu opotřebení návaru s různým podílem fází.

návarová slitina; abrazívní opotřebení; mikrostruktura; navařování

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