Tribological behavior of four types of filler metals for hard facing under dry conditions

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Abstract

Purpose – The purpose of this study is to show which filler metal is the best for hard facing. Because the quality of the surface layer has a great influence on the working life of parts, the purpose was to extend the working life of parts exposed to intensive wear. The tested hard-faced models were made of low carbon steel to save the expensive base metal and to analyze the possibilities of extending the service life of existing structural parts.

Design/methodology/approach – Samples were prepared from plates hard faced with various filler metals. Samples were then subjected to experimental testing – testing of tribological properties and hardness and microstructure. Testing was done in conditions similar to real ones – with a sliding speed of 0.25, 0.5 and 1 m/s and with a load of 50, 75 and 100 N and in most rigorous dry conditions. Research was done by using a combination of experimental and theoretical approaches.

Findings – The paper shows the results of the experimental testing of four different filler metals aimed for hard facing of parts exposed to highly intensive wear. Results shown that CrWC 600 alloy is the most favorable filler metal for hard facing of parts such as those of construction mechanization and those subjected to intensive abrasive wear at stone mines.

Practical implications – All obtained results are real and fully applicable, as there is a huge industrial need for these types of technologies. With the application of these technologies, beside money savings, the working life of parts can be significantly extended.

Originality/value – The research presented in this paper was conducted because of the lack of results from this area in Serbia and because of the necessity for application of obtained results in companies for road maintenance and stone excavation in the region of Šumadija, Serbia.

Keywords Wear resistance, Friction coefficient, Filler metals, Hard facing, Hardness and microstructure, Wear volume, Microstructure

Paper type Research paper

1. Introduction

Numerous working parts during exploitation are exposed to various types of complex tribological processes and wear. It is hard to determine which of the wear mechanisms are dominant and which lead to the biggest damages. Usually, damages are consequences of coupled actions of several wear mechanisms. Therefore, it is necessary to use higher-quality materials, which are resistant to wear and can produce more working hours for the concrete machine part. Because the manufacturing of large parts or the whole structures of high-quality materials would be too expensive, the problem could be solved by the application of hard facing. It enables reparation of damaged parts or manufacturing of new parts by depositing high-quality materials on cheaper ones. In that way, one saves not only material and money but also the time needed for revitalizing damaged parts, shortening the downtimes, etc.

Truhan *et al*. (2007) dealt with problems of hard-face claddings for deep-hole drilling. Results have shown that there is an excellent correlation between friction coefficient and wear, by weight loss, of both the cladding and the casing alloys. There was also a good direct correlation between the wear of both the cladding and the casing. In addition, Kang *et al*. (2014) have shown that hard facing could successfully be used for reparation of parts in agricultural mechanization – rotary tiller for soil preparation. Tiller blades are subjected to

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extreme surface wear, particularly in dry sand, which considerably affects its service life. The aim was to examine the effects of hard facing on the extent of wear and the wear characteristics of the tiller blades. The results showed that the average wear rate of the un-hard-faced blade was 7.08 gm/acre, while that of the hard-faced blade was 5.02, 4.3, 2.84 and 4.22 gm/acre as indicated by the field test results. This is an indicator that a significant improvement was observed in the wear protection provided by hard facings. Microstructural and chemical compositions of used alloys have a large influence on the quality of the hard-faced joints. Thus, Liu *et al*. (2013) analyzed the effect of boron on the microstructure and wear properties of hard-facing alloys. Hard facing was done by a new type of Fe–Cr–Ti–C alloy by using self-shielded metal-cored wire with varying boron content. Phase composition and microstructure of the as-prepared alloys were characterized by X-ray diffraction and scanning electron microscopy methods. The results showed that hardness increases rapidly with an increase in the boron content up to 0.99 Wt.%, and then increases more slowly; the main conclusion is that boron improves the wear resistance of the alloys. The positive effect of boron on the microstructure and wear resistance was also confirmed by Cui *et al*. (2015) by testing Fe-Cr-B alloys under dry conditions. According to a similar procedure (Laurila *et al*., 2013), tribological properties of the vanadium-based filler metals for hard facing are shown. When hard silicon oxide particles were used, abrasive wear resistance of the tested coating material was found to be low. Also, heat treatment above 950°C leads to a reduction in the impact wear resistance. Determination of the influence of molybdenum, vanadium and nickel on tribological properties of materials aimed for hard facing was also done by Lin *et al*. (2010). Findings show that addition of V, Mo and Ni obviously affects the hardness and indentation fracture (KC) of primary carbides and eutectic colonies. Besides the chemical elements, the microstructure of materials and temperature have a large influence on mechanical properties. That was the subject of research Varga *et al*.'s (2011) paper, where it was shown that wear rates and mechanisms at high temperature cannot be directly correlated to wear at ambient temperature; also, the material's microstructure has a crucial influence on the wear behavior. Hence, the more expensive Ni-based alloy with tungsten carbide reinforcement does not necessarily exhibit better wear resistance. Because in this paper, materials based on C and Cr were used, the research presented by Chang *et al*. (2010) was analyzed, where it was shown that with increasing C content in hard-facing alloys, the fraction of $(Cr,Fe)_7C_3$ carbides increased, while their size decreased. The hardness of hard-facing alloys increased with an increase in the fraction of $(Cr,Fe)_7C_3$ carbides, which influence the abrasive properties and the wear resistance of alloys aimed for hard facing (HF). The same conclusion can be drawn from research of Anasyida and Nurulakmal (2015) who also analyzed influence of chromium coating on wear resistance of working parts. Mitrović *et al*. (2012) and Zavos Nikolakopoulos (2015) also showed that hard chrome-coated samples have higher wear resistance in comparison to those not coated. While, Lin and Asplund (2014) dealt with problems of locomotive wheels' degradation (wear). The results can be useful to monitor and compare wear rate of different working systems.

In this paper, four different filler materials were used. These materials are aimed for hard facing of the parts exposed to intensive impact and abrasive wear, such as bucket teeth of the excavator (Lazarević *et al*., 2015), parts for terrain leveling (Nedeljković *et al*., 2008), mixer blades used in asphalt bases (Lazić *et al*., 2008), teeth of stone mils (Jozić *et al*., 2015), industrial gears (Marković *et al*., 2011), forging dies (Arsić *et al*., 2015; Hawryluk *et al*., 2014), etc. During the exploitation, they are in contact with various types of stones (Lazić *et al*., 2015), and they are exposed to intensive wear, leading to severe surface damages. Our earlier investigations showed that the working life of parts was extended because of the better wear resistance in comparison to new parts (Lazić *et al*., 2011).

2. Filler metals properties and hard-facing technology

Filler metals were selected on the basis of the purpose of the hard-faced parts and on the characteristics that the material possesses. Tested filler metals are aimed to work in extreme wear conditions. In addition, besides wear, very often, the impact load is present, which can lead to fatigue of surface layers of working parts. Steel alloys with high carbon and chromium content were the chosen materials. The chemical composition of used metals is given in Table I. Hard facing was done by the manual metal arc (MMA) welding method in three passes and three layers (Figure 1). Samples were preheated at 300°C, and hard facing was done according to parameters given in Table II.

Hard-faced models [Figure 1(a)] are used to cut the blocks for tribological test [Figure 1(b)] and metallographic samples – blocks cut out of them, as shown in Figure 1(c). Here it is very important to know that the height of all the hard-faced samples was within the range of 8.5 to 11 mm [Figure 1(a)]. That height enabled reliable cutting out of the blocks from the hard-faced layers, i.e. preparation of blocks within the adequate tolerances and with prescribed parallelism of samples sides.

Hardness has been measured on the surfaces of metallographic samples in different directions necessary to estimate the microstructure of characteristic surfaced zones. Samples were chosen to be geometrically similar to hard-faced part, and they were made of well weldable steel S355J0 (by DIN St St52-3U). A large number of parts in construction machinery are made of S355J0 steel; this is why this steel was used as the base metal, but because of its poor wear resistance, alloying (Thongchitrugsa *et al*., 2014) or hard facing is needed.

3. Experimental investigations

Experimental investigations included hardness measurement along three lines perpendicular to the hard-faced surface, investigation of the microstructure of characteristic zones and tribological testing to determine the wear resistance of the hard-faced layers.

3.1 Hardness and microstructure

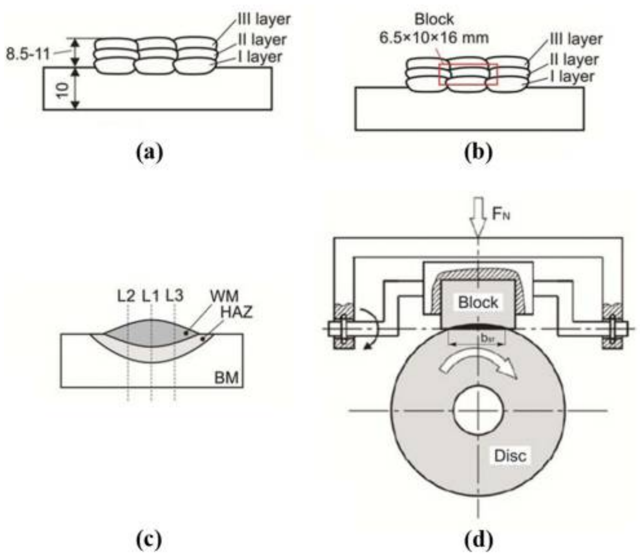
Hardness was measured along the three directions perpendicular to the hard-faced layers' surface, on samples prepared from the weld metal, according to Figure 1(d). All the zones of the hard-faced layer (weld metal – WM, heat affected zone – HAZ and in the base metal – BM) (Figure 2) were measured. Besides the hardness, for every FM, the

Table I Chemical composition of base metal and filler metals

Steel/Electrodes	Alloying elements [%]										
	C	Si	Mn	P	S	Cr	Mo	W	Cu	CEV	Hardness, HRC/HV
S355J0	0.2	0.55	1.4	0.035	0.035	–	–	–	0.55	0.47	≈ 22/240
E DUR 600 DIN 8555: E 6-UM-60	0.5	–	–	–	–	7.5	0.5	–	–	–	≈ 56/600
CrWC 600 DIN 8555: E 10-UM-60-C	4.0	–	–	–	–	26.0	–	4.0	–	–	≈ 58/650
INOX B 18/8/6[a]	0.12	0.8	7.0	–	–	19.0	9.0	–	–	–	–
E Mn17Cr13	0.6	–	16.5	–	–	13.5	–	–	–	–	≈ 50/500

Note: [a] Mild austenite electrode aimed for deposition of interlayer in order to increase plasticity of the joint and to replace preheating.
Source: Marković *et al.* (2011), Catalogue of filler materials Electrode Jesenice, Slovenia (2015)

Figure 1 (a) Order of layers' deposition; (b) blocks for tribological "block-on-disk" contact; (c) metallographic ground slit; (d) "block-on-disc" contact

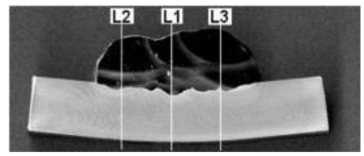


microstructure was determined. Results are presented as diagrams in Figure 3.

The microstructure of all the characteristic zones of the surfaced layer was analyzed on the same samples that were used for measuring the hardness; however, we present the results for the surfaced layer's structure. An optical microscope with magnifications 200× and 500× was used for the analysis. Samples were etched using 3 and 4 per cent nital and Vielle solutions, respectively, when necessary.

Based on the optical metallographic analysis, it could be assumed that in the part of the surfaced layer of Sample # 1 (E DUR 600), immediately next to the melting line (in the dissolution zone), the bainite micro constituent, with dendritically excreted carbides, is predominant. Analysis of Samples # 2 and # 3 (CrWC 600) shows the presence of the

Figure 2 Sample No. 1 – Directions of hardness measurement



microstructure with a prominent dendrite structure of casting and excreted carbides. Because this filler metal belongs to a group of highly alloyed (special) metals with a high content of chromium (26 per cent) and tungsten (4 per cent), the sample had to be etched with the 4 per cent Vielle solution to obtain the needed surface condition (Small *et al.*, 2008). Sample # 4 was also characterized by the large grain cast microstructure with primarily inhomogeneous dendrites of austenite. The dark color probably represents the $(Fe,Mn)_3C$ carbides excreted at grain boundaries.

Because of limitations in the micro structure estimates based on the light microscope analysis, to be absolutely certain about the present micro structures in samples, one must also perform the scanning electron microscopy analysis.

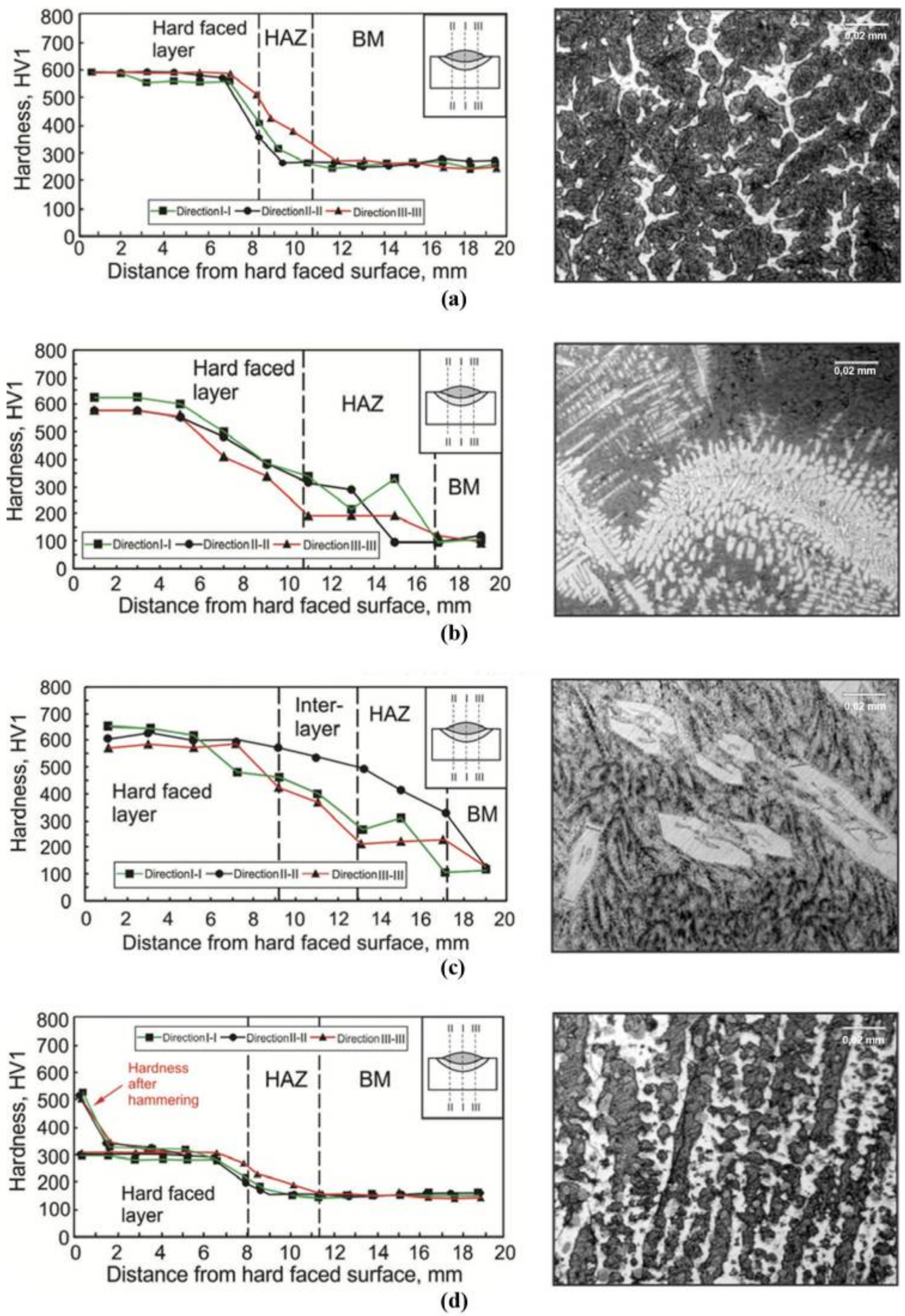
3.2 Tribological investigations

Tribological investigations were performed in the Laboratory for Tribology at the Faculty of Engineering in Kragujevac using the tribometer TR-95. The objectives of those tests were to determine the wear resistance of joint base metal – hard-faced metal. Samples for tribological testing, as prismatic blocks with dimensions 6.5 × 10 × 16 mm, were taken from the hard-faced layer. All samples were grounded and the disc was grounded after each testing. Here, one should keep in mind the degree of mixing – dilution of the filler metal by the base metal, which inevitably occurs and in the majority of cases, leads to a decrease in the useful properties of the hard-faced layer, like hardness and wear resistance. Thus, the objective of authors was to decrease, as much as possible, this dilution degree of the hard-faced layer by selecting the adequate hard-facing parameters. In addition, this was also

Table II Hard-facing parameters for the MMAW procedure

BM thickness [mm]	Electrode designation by producer	Electrode core diameter d_e [mm]	Hard-facing current I [A]	Voltage U [V]	Hard-facing speed v_z, [mm/s]	Driving energy q_l [J/cm]
10	E DUR 600	3.25	120	25	≈2.356	11,460
	CrWC 600		125	25	≈1.91	14,023
	INOX B 18/8/6		110	24	≈1.93	12,548
	E Mn17 Cr13		130	25.5	≈2.46	11,985

Figure 3 Hardness distribution and microstructure of four filler metals



Notes: (a) E DUR 600; (b) CrWC 600; (c) CrWC 600; Interlayer INOX B 18/8/6; (d) E Mn17 Cr13

taken into account when the samples were taken from the middle of the first layer and upwards, so that the diluted layer of the metal was avoided. In the opposite case, the blocks aimed for tribological investigations would have contained elements of the base metal, which definitely would have led to a change in the chemical composition and almost surely would have influenced the obtained results. During the testing, "block-on-disk" contact was realized [Figure 1(d)]. The disc used in contact with tested samples was made of a high-speed tool steel, with diameter of 35 mm and a thickness of 6.35 mm [the same as the width of 6.35 mm at test sample block as shown in Figure 1(b)]. External variables were the contact force and the sliding speed. Because the working parts hard faced with these filler metals work without lubrication, tribological tests were executed in dry conditions. Prior to testing, the topography of discs and blocks was measured on a digital measurement system – Taylor & Hobson Talysurf 6 – and the arithmetic average roughness (Ra) of the characteristic surfaces is shown in Table III.

Table III Arithmetic average roughness (Ra) for used samples

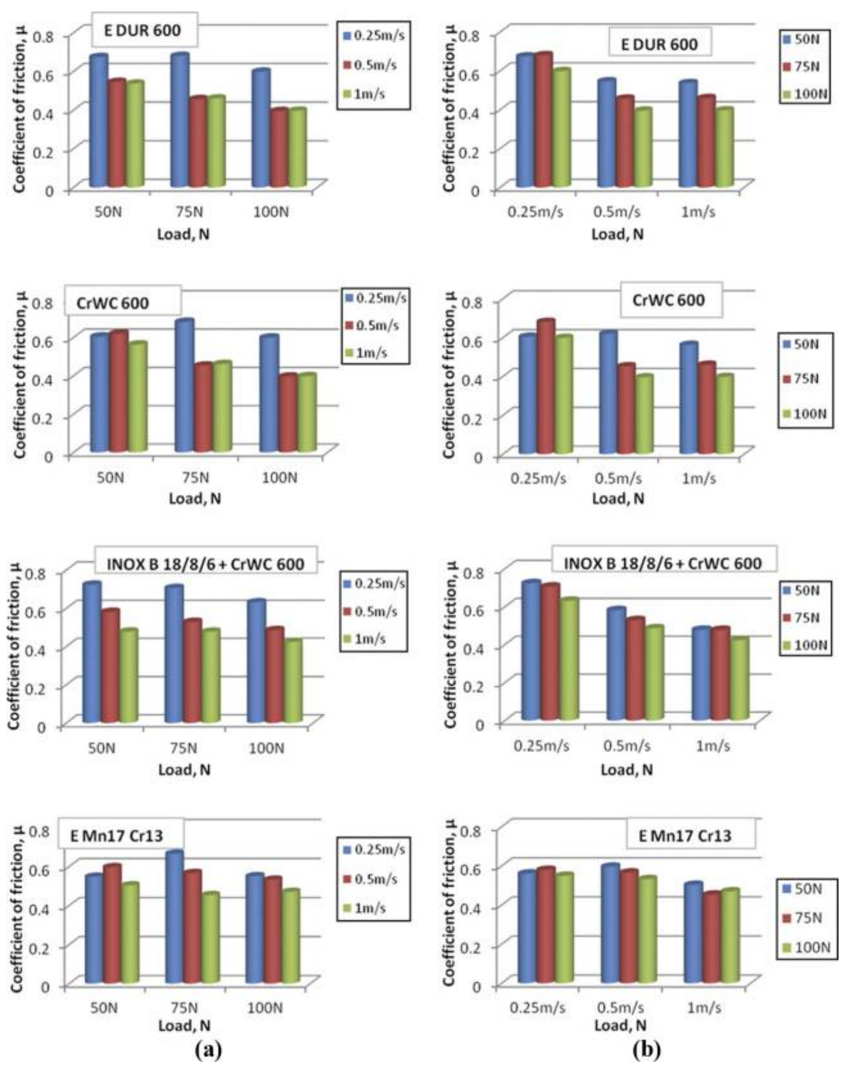
Samples	Arithmetic average roughness, Ra, μm			
	1 - E DUR 600	2 - CrWC 600	3 - INOX 18/8/6 + CrWC 600	4 - E Mn17 Cr13
	0.43	0.35	0.47	0.45

The experiment assumed the simulation of contact by using three different sliding speeds (0.25 m/s, 0.5 m/s and 1 m/s) and three different loads (F_N = 50 N, F_N = 75 N and i F_N = 100 N). The parameter for contact duration was the sliding distance of 300 m. Parameters that were followed during the process were: the friction coefficient, wear volume and specific wear volume. The wear behavior of the block was monitored in terms of the wear scar width, using the wear scar width and the geometry of the contact pair to determine the wear volume (expressed in mm^3) over the sliding distance.

Table IV Mean values of the friction coefficient

Friction coefficient μ	E DUR 600 Sliding speed, m/s			CrWC 600 Sliding speed, v, m/s			INOX 18/8/6 + CrWC 600 Sliding speed, v, m/s			E Mn17 Cr13 Sliding speed, v, m/s		
Load, N	0.25	0.5	1.0	0.25	0.5	1.0	0.25	0.5	1.0	0.25	0.5	1.0
50 N	0.675	0.546	0.534	0.604	0.618	0.562	0.723	0.581	0.489	0.547	0.596	0.503
75 N	0.681	0.457	0.460	0.679	0.452	0.459	0.706	0.528	0.477	0.665	0.566	0.453
100 N	0.599	0.395	0.397	0.598	0.395	0.396	0.631	0.485	0.423	0.549	0.532	0.469

Figure 4 Mean values of the friction coefficients at different loads (a) and sliding speeds (b)



4. Results and discussion

After testing, the wear scar width of all samples was determined using microscope UIM 21 with a magnification of 50×. Based on obtained values, the wear volume and specific wear volume were calculated, for a sliding distance of 300 m. During testing, the friction coefficient was recorded, and the results are shown in Table IV and in Figure 4. Steady state of friction coefficient is reached almost from the very beginning of the sliding, whereas the obtained values are characteristic for sliding without the application of lubrication. The results of the wear volume obtained by experiment are shown in Figure 5.

Analyzing the obtained results shown in Figure 4, it can be said that the friction coefficients in all cases increased when the load and sliding speed are lower. The largest values of the friction coefficient were obtained in case when the sliding speed was 0.25 m/s and mostly with a load of 50 N, when values for the friction coefficient were reaching 0.7. By analyzing the real working conditions, one can say that parts surfaced by these materials operate in much rigorous conditions, i.e. higher sliding speeds (about 1 m/s) and larger forces ($F > 100$ N), leading to the conclusion that the tested materials possess better frictional properties. According to the Stribeck curve, and according to the behavior of the friction coefficient with an increase in the sliding speed (slight decrease in the friction coefficient), it can be assumed that the test conditions in our study are in the domain of boundary friction.

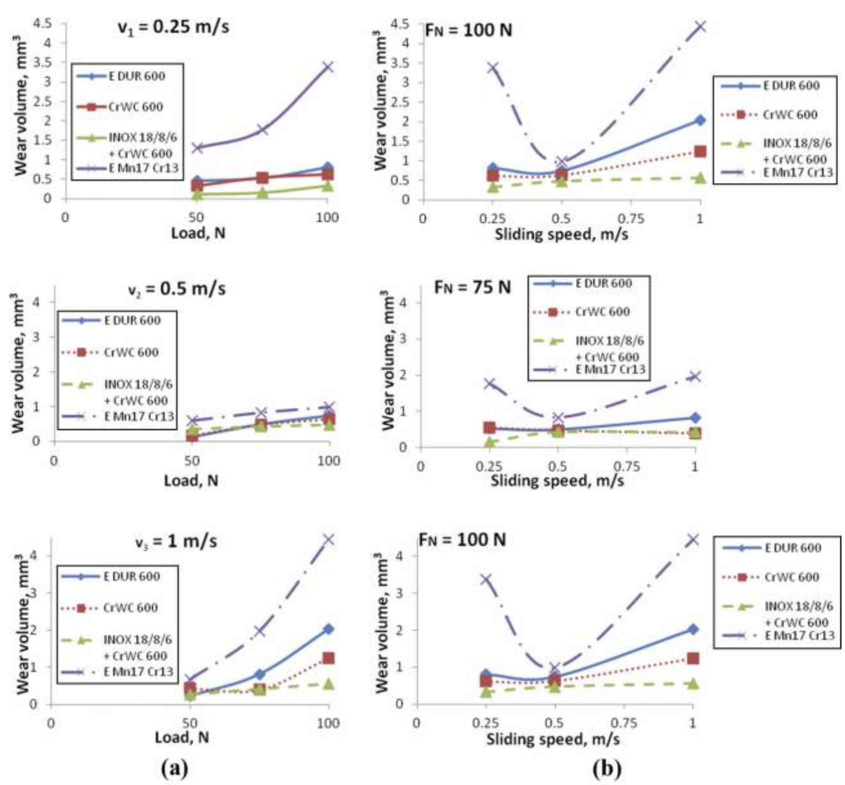
In the end, the worn samples' surface was recorded using a light microscope (MEIJI TECHNO MT8500). Characteristic damages and wear scars of all tested specimens are presented in Figure 6.

It is clear that abrasive wear was the governing wear mechanism, which was confirmed by clearly visible parallel scratches and abrasive grooves in the direction of sliding. Visual inspection by the optical microscope revealed that there was no visible damage on the disc surface, because of its higher hardness, as predicted. Accordingly, disc wear can be assumed as negligible.

By comparison of the obtained images (wear scars), the distinct difference in the wear scar levels of different materials is obvious. It can be said that in the contact zone, pulling out of the material occurred, which later can behave as the abrasive particles and can have an influence on further increase in surface damages. This surface appearance is characteristic for materials with high hardness. Abrasive wear mechanism can be clearly seen in Figure 6. Deep scratches and grooves, together with cracks originating from the detachment of larger pieces of the surface material, are characteristic of E DUR 600 and E Mn17 Cr13 (denoted as D in Figure 6), while for CrWC 600, the presence of pitting cracks (denoted as P in Figure 6) is characteristic.

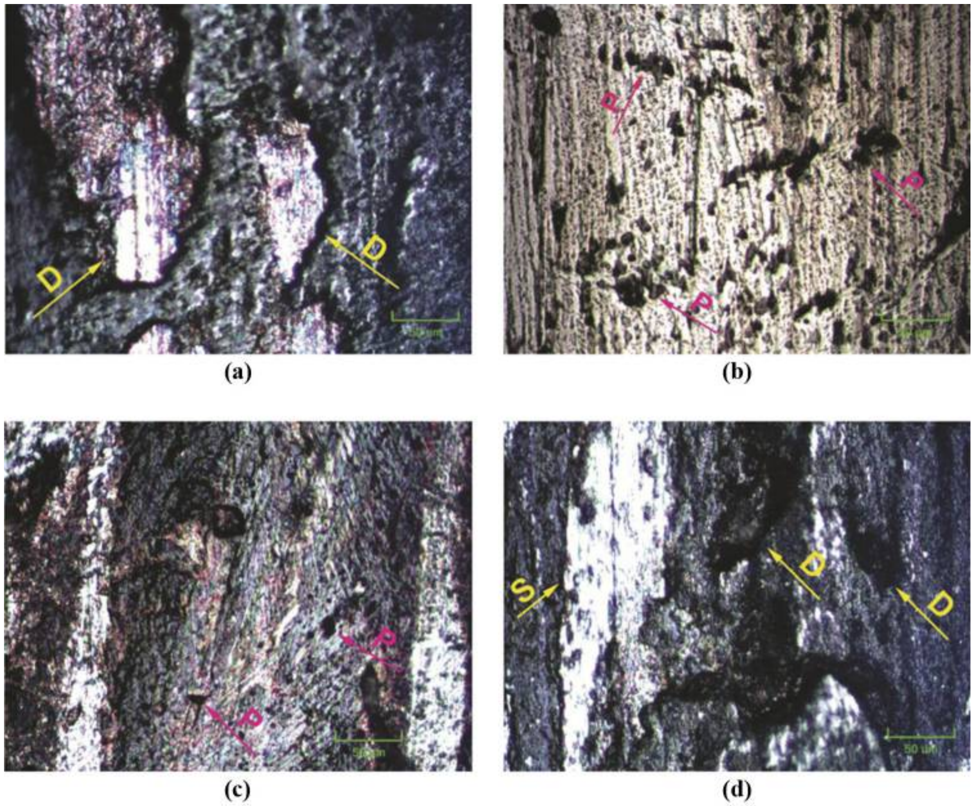
The surface of worn samples and the wear scars was recorded with a magnification of 100×. Surface damages (Figure 6) are very different depending on the material. E DUR 600 alloy has a specific wear type, for which the phenomenon of scratching and cracks and material detachment from the surface is characteristic. Appearance of a crack is most probably because of material detachment.

Figure 5 Wear volume of the tested samples



Notes: (a) At different sliding speeds; (b) at different loads

Figure 6 Damages of the samples



Notes: (a) E DUR 600; (b) CrWC 600; (c) INOX 18/8/6 + CrWC 600; (d) E Mn17 Cr13; F_N = 100 N; v1 = 0.25 m/s; magnification 20×; D = material detachment, S = scratches, P = pitting

The created cracks, in most cases, propagate horizontally in the surface layer, disturbing metal continuity and causing an increase in stress and “wedging in” of abrasive particles. Later, the detached material particles act as abrasives and cause an even larger and more prominent wear, as they have high hardness. Further material degradation is caused by increased pressure in the surrounding zones of the material.

When the alloy CrWC 600, with or without an interlayer, is concerned, it is characteristic wear in the form of pitting. Small pits appear at points of high pressure because of which the initial micro cracks are propagating. During the contact, these micro cracks continue to grow until the detachment of material particles. In the case when the interlayer was applied, the conclusion is that it can act as a shock-absorbing layer that can have an influence on the impact stability.

Also, for E Mn 17 Cr 13, the phenomenon of scratching and material detachment, i.e. spots where the material was “torn” from the surface, is characteristic.

5. Conclusion

Analyzing the results, it can be concluded that the best tribological properties and wear resistance have the filler metal designated as CrWC 600 (sample #3), deposited with or without an austenitic interlayer. The best results were obtained using all three sliding speeds of 0.25, 0.5 and 1 m/s and almost all used loads. The function of the interlayer is to absorb impacts during exploitation, as well as to replace preheating when it is impossible to apply it (while it is predicted by the welding technology).

In the case of other samples – #1 and #2 – the main conclusion is that their wear resistance is a little bit lower than that for Sample # 4. The worse wear properties have a filler metal with high manganese content – Sample #4. It should be taken into account that this filler metal is aimed for cold hardening because of hammering or exploitation (deformation induced the transformation of austenite into martensite), leading to an increase in hardness. However, the conclusion is that it also cannot drastically affect the tribological properties of this filler metal and that this filler metal should not be recommended for reparatory hard facing of parts exposed to intensive abrasive wear and impact loads.

In addition, a general remark should be made about behavior of the friction coefficient during testing. The friction coefficient was in the range from 0.395 to 0.723 for all the tested materials, and with an increase in load (Figure 4a) and sliding speed (Figure 4b), a decrease in the friction coefficient was observed.

References

Anasyida, A.S. and Nurulakmal, M.S. (2015), “Wear behaviour of carbon steel cutting wheel thermal flame sprayed with chromium carbide”, *Industrial Lubrication and Tribology*, Vol. 67 No 2, pp. 93-98.

Arsić, D., Lazić, V., Samardžić, I., Nikolić, R., Aleksandrović, S., Djordjević, M. and Hadzima, B. (2015), "Impact of the hard facing technology and the filler metal on tribological characteristics of the hard faced forging dies", *Tehnički Vjesnik – Technical Gazette*, Vol. 22 No. 5, pp. 1353-1358.

Catalogue of filler materials Electrode Jesenice, Slovenia (2015).

Chang, C., Chen, Y. and Wu, W. (2010), "Microstructural and abrasive characteristics of high Carbon Fe–Cr–C hardfacing alloy", *Tribology International*, Vol. 43 Nos 5/6, pp. 929-934.

Cui, G., Wei, J. and Wu, G. (2015), "Wear behavior of Fe-Cr-B alloys under dry sliding condition", *Industrial Lubrication and Tribology*, Vol. 67 No. 4, pp. 336-343.

Hawryluk, M., Marciniak, M. and Misiun, G. (2014), "Possibilities of investigating abrasive wear in conditions close to those prevailing in industrial forging processes", *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, Vol. 16 No. 4, pp. 600-607.

Jozić, S., Bajić, D. and Stoić, A. (2015), "Flank wear and surface roughness in end milling of hardened steel", *Metalurgija*, Vol. 54 No. 2, pp. 343-346.

Kang, A.S., Cheemaa, G.S. and Singla, S. (2014), "Wear behavior of hardfacings on rotary tiller blades", *Procedia Engineering*, Vol. 97 No. 1, pp. 1442-1451.

Laurila, J., Milanti, A., Nurminen, J., Kallio, M. and Vuoristo, P. (2013), "Microstructure and wear behaviour of a vanadium carbide reinforced weld coating", *Wear*, Vol. 307 Nos 1/2, pp. 142-149.

Lazarević, Z., Aranđelović, I. and Kirin, S. (2015), "An analysis of random mechanical failures of bucket wheel excavator", *Structural Integrity and Life*, Vol. 15 No. 3, pp. 143-146.

Lazić, V., Arsić, D., Nikolić, R., Hadzima, B. and Mutavdžić, M. (2015), "Experimental determination of mechanical characteristics of four types of stones and their influence on the construction machinery parts wear", *Advanced Materials Research*, Trans Tech Publications, Zurich, Vol. 1100, pp. 178-184.

Lazić, V., Jovanović, M., Milosavljević, D., Mutavdžić, M. and Čukić, R. (2008), "Choosing of the Most suitable technology of hard facing of mixer blades used in asphalt bases", *Tribology in Industry*, Vol. 30 Nos 1/2, pp. 3-10.

Lazić, V., Mutavdžić, M., Milosavljević, D., Aleksandrović, S., Nedeljković, B., Marinković, P., Čukić, R. (2011), "Selection of the most appropriate technology of reparatory hard facing of working parts on universal construction machinery", *Tribology in Industry*, Vol. 33 No. 1, pp. 18-27.

Lin, C.M., Chang, C.M., Chen, J.H. and Wu, W. (2010), "The effects of additive elements on the microstructure characteristics and mechanical properties of Cr–Fe–C Hard-facing alloys", *Journal of Alloys and Compounds*, Vol. 498 No. 1, pp. 30-36.

Lin, J. and Asplund, M. (2014), "Comparison study of heavy haul locomotive wheels' running surfaces wearing", *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, Vol. 16 No 2, pp. 276-287.

Liu, D., Liu, R., Wei, Y., Ma, Y. and Zhu, K. (2013), "Microstructure and wear properties of Fe–15Cr–2.5Ti–2C–xB wt.% hardfacing alloys", *Applied Surface Science*, Vol. 271 No. 1, pp. 253-259.

Marković, S., Milović, L.J., Marinković, A. and Lazović, T. (2011), "Tribological aspect of selecting filler metal for repair surfacing of gears by hard facing", *Structural Integrity and Life*, Vol. 11 No. 2, pp. 127-130.

Mitrović, S., Babić, M., Adamović, D., Živić, F., Džunić, D. and Pantić, M. (2012), "Wear behaviour of hard Cr coatings for cold forming tools under dry sliding conditions", *Tribology in Industry*, Vol. 34 No. 1, pp. 44-48.

Nedeljković, B., Babić, M., Mutavdžić, M., Ratković, N., Aleksandrović, S., Nikolić, R. and Lazić, V. (2008), "Reparatory hard facing of the rotational device knives for terrain leveling", *Journal of the Balkan Tribological Association*, Vol. 16 No. 1, pp. 46-57.

Small, K.B., Englehart, D.A. and Christman, T.A. (2008), "Guide to etching specialty alloys", *Advanced Materials & Processes (ASM International)*, Vol. 166 No. 2, pp. 32-37.

Thongchitrugsa, N., Chianpairot, A., Hartung, F. and Lothongkum, G. (2014), "Effect of molybdenum on wear resistance of Cr-Nb Hard-faced S355JR steel", *Materials Testing*, Vol. 56 No. 3, pp. 191-197.

Truhan, J., Menon, R., LeClaire, F., Wallin, J., Qu, J. and Blau, P. (2007), "The friction and wear of various hard-faced claddings for deep-hole drilling", *Wear*, Vol. 263 Nos 1/6, pp. 234-239.

Varga, M., Winkelmann, H. and Badisch, E. (2011), "Impact of microstructure on high temperature wear resistance", *Procedia Engineering*, Vol. 10 No. 2, pp. 1291-1296.

Zavos, A. and Nikolakopoulos, P. (2015), "Tribological characterization of smooth and artificially textured coated surfaces using block-on-ring tests", *FME Transactions*, Vol. 43 No. 3, pp. 191-197.

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