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Comparison of two-body abrasive wear resistance of high chromium boron-containing Fe–C-B–13wt.%Cr-Ti alloy with incomplete replacement of Cr for Cu the Fe-C-B-4wt.%Cr-7wt.%Cu–Ti alloy

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Abstract

Hardfacing process commonly employed because of its low cost and high efficiency. The microstructure of an two sample of deposited metal by X-ray diffraction, scanning electron microscope (SEM). In this research, the mechanical and tribological properties of two deposited metal of Fe–C–Cr–B–Ti alloying systems, high chromium 140Cr13Si1MnBTi alloy, and low chromium and high copper 110Cr4Cu7TiVBAl alloy hradfecing by flux-cored arc welding process (FCAW) was studied. It provided a low content of chromium (4 wt.%) and a high content of copper (7 wt.% Cu). Results of the studies had showed that the introduction of exothermic addition (CuO–Al) to the core filler of the flux–cored wire electrode, change melting characteristic and provides the highest resistance of the deposited metal to abrasion wear due to additional alloying by copper and reduction in grain size.

Key words: hardfacing, two-body abrasive wear, Fe–C–Cr–B–Ti alloys, self-shielded flux–cored arc welding, exothermic addition.

Introduction

The competitiveness of machines operated at mining and processing plants and enterprises engaged in the processing of solid materials, in addition to price and energy consumption, is also determined by such indicators as productivity and reliability (technological breaks or emergency stops for scheduled and emergency repairs). The latter depends on the life of the parts, which are primarily short-lived which are parts subjected to intense wear [1]. The cost of worn parts in mining is approximately the same as the cost of maintenance [2]. In engineering abrasive wear is probably the most crucial type of wear, because it contributes to almost 63% of the wear costs [3]. The manufacture of tools from wear-resistant material is impractical both from an economic point of view and from a technological point of view. Since in most cases wear acts locally (on a certain area of the surface), the rest of the structure can be made from cheaper structural materials. Therefore, it is advisable to apply a reinforcing layer locally. Different technologies are used for coatings application. Hardfacing techniques are employed mainly to extend or improve the service life of engineering equipment components. In addition, hardfacing is also used to restore worn surfaces of parts, thereby extending the life of such parts. The flux-cored wires segment is the most significant by type segment in the global market, and is expected to be the first preference for new entrants due to their high deposition rate, efficiency in delivering work, high quality of the deposited metal and arc visibility [4].

During a long period the hypereutectic Fe-Cr-C hardfaced coating was used for strengthening and repair of parts and units subject to abrasive wearing. Its high wear resistance is due to availability of hard M_7C_3 carbides. However, these alloys are subject to cracking during hardfacing. According to explanation of Yılmaz [5] deposited metal cracking during hardening happens, because M_7C_3 carbide has a very high brittleness and low fracture toughness. For this reason there is a great interest in alternative alloying systems implementation. To improve the toughness of hypereutectic overlay would inevitably sacrifice its wear resistance because reducing the amount of carbide hard phase is the solely effective way [6]. However, this will inevitably lead to a decrease epy abrasive wear resistance. Therefore, the use of alternative alloys is of interest, among which alloys with boron, which were first proposed by Lakeland, can be distinguished [7]. The matrix and wear-resistant phase here could be controlled by changing carbon and boron concentrations. Fe–C–B-Cr alloys has excellent wear resistance, good corrosion resistance, and oxidation resistance [8]. The more widespread by Fe-Cr-B-C and Fe-Cr-B-C-Ti system alloys, which have the best mechanical properties and wear resistance [10-13]. Available information suggests that the abrasive wear resistance of materials depends on factors like microstructure (their size and content), and mechanical properties of materials [14].

Abrasive wear can be classified according to the interaction conditions as two-body and three-body abrasive wear [15]. Two-body abrasion is caused by hard protuberances on the counterface or hard particles attached to it, while in three-body abrasion the hard particles are free to roll and slide between two, perhaps dissimilar, sliding surfaces.

The purpose of the work

The purpose of the work was to make a comparative researches of wear resistance of 110Cr4Cu5TiVBAl alloy having a low chromium content and high copper content with 140Cr15TiSi1MnVB alloy having a high chromium content in two-body abrasive wear conditions.

Hardfacing technology

The FCAW-S of 4 mm diameter was used for investigations. The hardfacing was carried out by three-layers on plates made from low carbon steel S 235 JRG2 EN 10025-2 with dimensions 10×100×200 mm on reverse polarity by A-874 automatic machine.

Weld deposition were realized as three-layered to minimize impact of mixing the layer with base material. Welding parameters where chosen to provide high deposition values (high deposition rate and low spattering factor) [16], as well as for low solution of the deposited metal with the base metal and providing welded bead optimal shape [17]. Thus, hardfacing was performed by FCAW-S were as follows: wire feed speed WFS=1.85 m/min, arc welding voltage U_a =28 V, travel speed TS=0.3 m/min, contact tip to work distance CTWD=45 mm, DCRP Polarity, temperature preheating T_p=250…300 °C. Average values of welding current when surfacing with flux-cored wire FCAW-S-140Cr15TiSi1MnVB was 410 A, while when surfacing with experimental flux-cored wire FCAW-S-110Cr4Cu5TiVBAl - 360 A.

The core powder of filler materials is composed of gas-slag-forming components (fluorite concentrate, rutile concentrate, calcium carbonate), deoxidizers components (ferrosilicon, ferromanganese), alloying components (metal chrome powder, boron carbide powder, graphite, ferrovanadium, titanium powder), exothermic addition component (oxide of copper GOST 16539 79, aluminium powder PA1 GOST 6058-73) and iron powder. The difference between filler materials was as follows: an equivalent amount of metal chrome powder was added to the flux-cored wire FCAW-S-140Cr15TiSi1MnVB instead of the exothermal addition (CuO-Al) components. The shell of the cored wire is made of steel H08A. H08A with 20 × 0.5 mm was filled with mixed powders and then compressed down to a diameter of 4 mm by rolling. The coefficient wire filling (filling factor) of the flux-cored wire electrode is 0.34-0.35.

There are 3 layers made during hardfacing. Each layer was formed by sequential deposition of weld bead with a partial overlap of the previous weld bead (1/3). Samples for microstructure analysis, mechanical properties investigation and two-body abrasive wear test where prepared by mechanical cutting from the deposited plates with subsequent surface preparation at cutting modes that do not lead to their overheating.

The methodology and parameters of the two-body abrasive wear test are given in Student et al [18]. The assumed reference sample is C45 (GOST 1050 88) in the annealed state having ε= 1.0. The tested material specific wear rate SWR is calculated using the Equation 1:

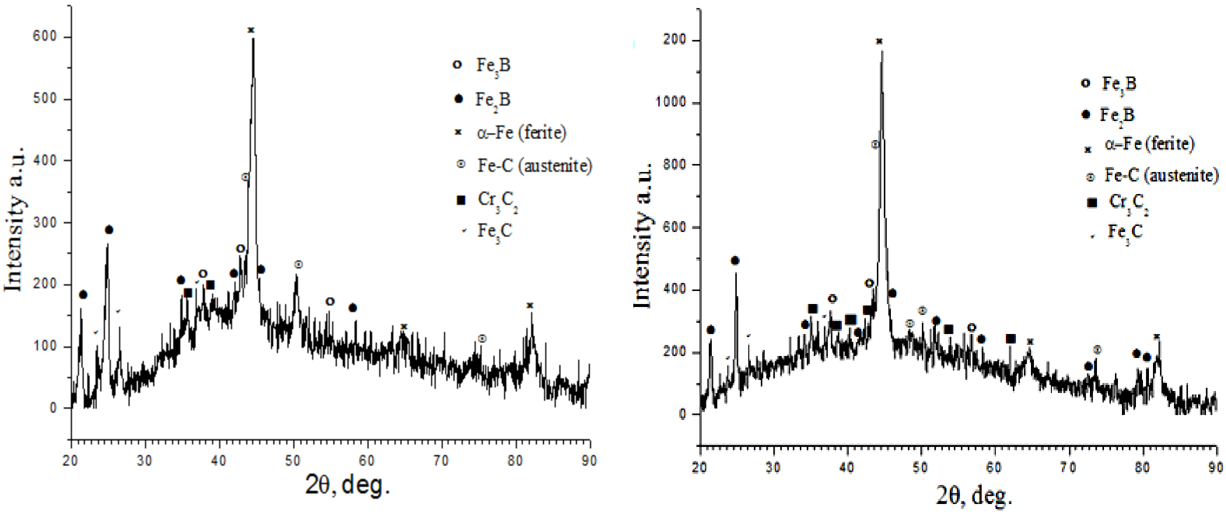
$$SWR = {}^{WV}\!/_{N \cdot L}, \tag{1}$$

WV – wear volume, mm^3;
N – normal load, N;
L – sliding distance, m.

Results of experimental studies

The analysis of the structure of coatings produced using electric arc and flame spraying revealed that the latter provides particle sizes which are 5-6 times smaller compared to traditional spraying. Consequently, the sizes and quantity of pores in EAS coatings decreased by 2-3 times.

Gas permeability is a structure-sensitive characteristic of coating, and there is a distinct enough dependence of it on open porosity [12 ~~8~~]. Under optimal spraying conditions, the porosity of EAS coatings is much lower than in the case of liquid metal spraying with cold air (2-4% and 9-11%, respectively), and the gas permeability is lower by approximately 30-40 times. This may be related to the essential decrease in the sizes of pore channels in coatings. Fig. 1 demonstrates the curves of pore size distribution for coatings obtained by electric arc and flame spraying.

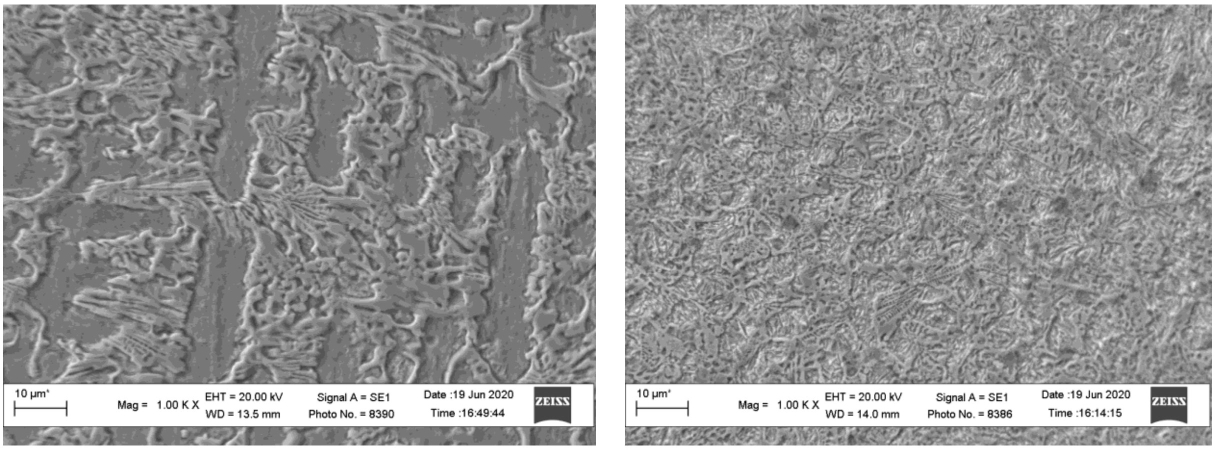


(a) (b)

Fig. 1. XRD pattern of deposited metal in 3 layers [1]: a) FCAW-S-140Cr15Si1MnBTi; b) FCAW-S-110Cr4Cu5TiVBAl with exothermic addition CuO - Al.

In weld metal deposited bt FCAW-S-140Cr15TiSi1MnVB and FCAW-S-110Cr4Cu5Ti1MnVB, apart from Fe_2B and $Fe_3(B,C)$ borides, the carbides Cr_2C_3 and TiC might be also present according to the reported results through X-ray diffraction analyses [4]. While the matrix is a eutectic of borides, α-Fe и γ-Fe. Whereas, in the high chromium alloy without copper, a large intensity of Cr_2C_3 carbide was observed. Whereas for the hardened layer FCAW-S-110Cr4Cu5Ti1MnVB, we observed a higher intensity for the Fe_2B boride, which indicated a larger proportion of this phase.

The microstructures of the deposited metal made using a scanning electron microscope (SEM) are shown in Fig. 2.



(a) (b)

Fig. 2. SEM images of the microstructures (×1000) deposited metal hardfacing by: (a) FCAW-S-140Cr15TiSi1MnVB and (b) FCAW-S-110Cr4Cu5Ti1VB with exothermic addition (CuO–Al).

The grain morphology parameters of the deposited metals were obtained according to the results of studies of the microstructure are presented in Table 1.

Table 1

The results of the analysis of grain length [1]

Sample	Number of analysed objects	Average value, µm	Minimum value, µm	Maximum value µm
140Cr15TiSi1MnVB	1488	15.3	2.6	719.8
110Cr4Cu5TiVBAl	1784	12.9	2.6	988.5

Data analysis showed that the introduction of an exothermic addition CuO-Al in the core filler of flux-cored wire electrode had a positive effect on the grain morphology. At that the average length of dendrites decreased from 15.3 µm to 12.9 µm. The introduction of exothermic additions into the core filler of flux-cored wire electrode has a positive effect on the grains morphology of the deposited metal. What could explain the formation of a large number of small non-metallic inclusions (NMI), which played the role of grain refiner/modifying agents.

Analysis and processing of the registered indentation curves allows to obtain mechanical properties of studied samples (Instrumented indentation hardness, modulus of elasticity, plasticity coefficient), calculated values are presented in Table 2.

Table 2

Mechanical properties determined by the depth-sensing indentation test

Flux-cored wire electrode	Instrumented hardness *HIT*, GPa	Elastic modulus *EIT*, GPa	Plasticity coefficient δ
FCAW-S-140Cr15TiSi1MnVB	9.938 ±3.054	176.987 ±13.697	0.766 ±0.045
FCAW-S-110Cr4Cu5TiVBAl	10.08 ±0.794	186.989 ±10.221	0.774 ±0.013

On Figure 3, a comparative diagram of tests on two-body abrasive wear of the studied alloys was shown.

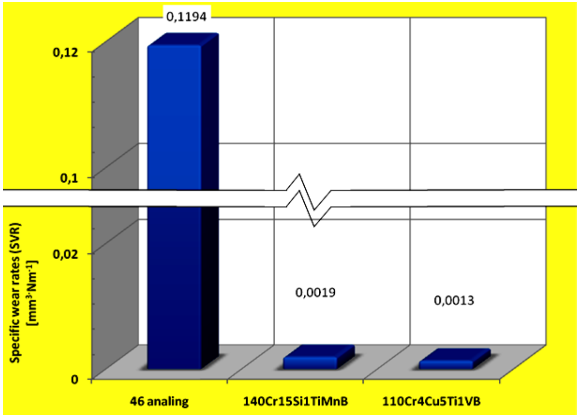
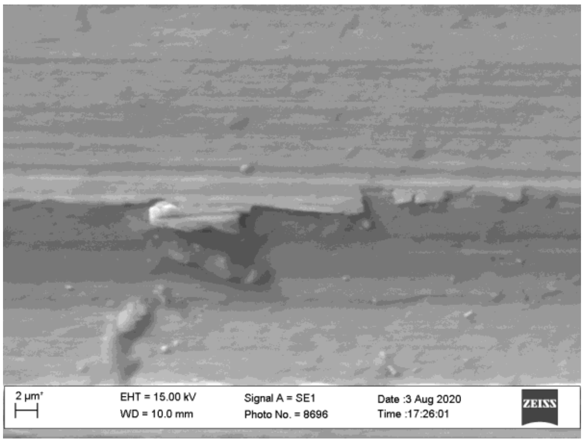
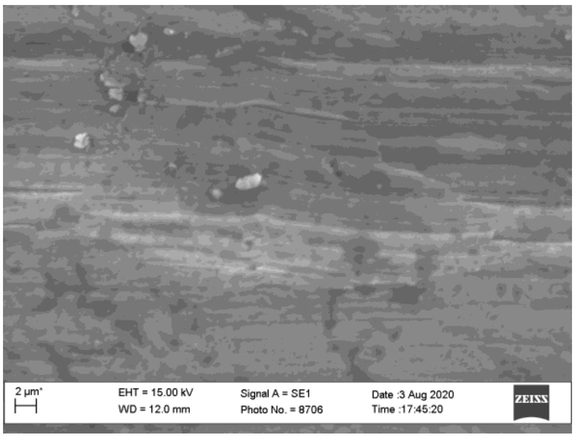


Figure 3. Two-body abrasive wear of deposited metals.

On Fig. 4, images of wear surfaces of welded metal samples were shown after two-body abrasive wear test was showing.



(a)



(b)

Fig. 4. Worn surfaces of the hardfacings: (a) FCAW-S-140Cr15TiSi1MnVB; (b) FCAW-S-110Cr4Cu5Ti1VB with exothermic addition.

Combination of micro-cutting, microcracing and micro-ploughing wear mechanisms was observed in reinforced two deposited metals tested under the two-body abrasive wear. Dominant wear pattern of FCAW-S-140Cr15TiSi1MnVB hardfaced surfaces was micro-cutting and microcracing (Fig. 4 (a)). At that, micro-cutting is the main mechanism of deposited metal 140Cr15TiSi1MnVB wearing. Dendritic structure with needle-like morphology led to such mechanism of metal wearing applied by FCAW-S-140Cr15TiSi1MnVB. Sharp tops of solid phase act as a stress concentrators, from which the deposited metal cracking with the further crumbling begins. For the reason that eutectic borides (Fe, Cr)$_2$B and Fe$_3$(B, C) were a barriers, resisting to wearing due to abrasive particles during contact of borides and abrasive, due to significant stresses after some time they were damaged and separated. Availability of cleavages at lines edges (Fig. 4 (a) indicates that the surface was damaged due to wearing by the fixed abrasive.

Samples wear pattern united two mechanisms: micro-cutting and micro-ploughing with predominant cutting (Fig. 4 (b)). Deposited metal received using proposed flux-cored wire FCAW-S-110Cr4Cu5TiVBAl had a higher wear-resistance to abrasive wearing. It is proved by the less specific wear rate SWR=0,0013 (mm$^3 \cdot$N^{-1}). Higher wear- resistance of the reinforcing layer applied by experimental flux-cored wire can be explained by the grain size reducing as well as an increasing of more damage-proof and plastic ferrite phase in the matrix. Due to the positive influence of the grain size reducing (first of all – borides needles size) the stress concentration in boride is reduced. It is not chipped during contact with abrasive particles. One of the factors for improving the resistance to impact load of the alloy may be its microstructure which included both the α-Fe phase and the γ-Fe phases. Increasing of ferrite phase in the matrix and eutectic allows to reduce the intensity of locations concentrations and due to this fact to reduce sensitivity of deposited metal to the stress accumulation.

Conclusions

1. Experimental studies comparing the effect of introduction of exothermic addition to the core filler of the flux-cored wire electrode on the structure, phase composition, mechanical properties of deposited metal and resistance to abrasive wear by two-body abrasive particles were performed.

2. The microstructure of the deposited metal (AW) was formed by a matrix of α'-Fe, M$_2$B borides, metal carboborides M$_3$(B, C) and TiC, associated with the high concentration of alloying elements of the Fe–C–Cr–B–Ti system. The eutectic matrix consists of M$_3$(C, B) carbides, together with ferrite and residual austenite.

3. Microhardness increasing was associated with the grain size decrease (dispersion structure) as per the Hall-Petch mechanism. The growth of the elasticity modulus was explained by a larger part of the ferrite phase in the matrix. The positive effect on the elastic modulus of the FCAW-S-110Cr4Cu7TiVBAl alloy, in which part of the chromium was replaced by copper, can be explained by an increase in the content of ferrite and austenite in the matrix.

4. Wear resistance of hardfacings tested under two-body wear conditions increased firmly introduction of exothermic addition CuO-Al to the core filler of the flux-cored wire electrode.

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Трембач Б.О., Винар В.А., Трембач І.О., Князєв С.А. Порівняння стійкості до зношування закріпленим абразивом високохромистого борвмісного сплаву Fe–C-B–13мас.%Cr-Ti з неповною заміною Cr на Cu сплав Fe-C-B-4мас.%Cr-7мас.%Cu–Ti.

Процес наплавлення широко використовується через низьку вартість та високу ефективність. Жлсдіджували мікроструктуру двох зразків наплавленого металу з використанням допомогою рентгенівської дифракції (XRD), скануючого електронного мікроскопа (SEM). У цьому дослідженні були визнасчені механічні властивості та трибологічні характеристики двох зразків наплавленого металу Fe–C–Cr–B–Ti системи легування, а саме сплаву з високим вмістом хрому 140Cr13Si1MnBTi та сплаву з низьким вмістом хрому та високим вмістом міді110Cr4Cu7TiVBAl, натоплені за допомогою процесу порошкових дротів (FCAW). Результати досліджень показали, що введення екзотермічної добавки (CuO–Al) до наповнювача серцевини електрода за рахунок еквивалентної кількості порошку металевого хрому у наповнювачі порошкового дроту змінює характеристику плавлення та забезпечує підвищення стійкісті наплавленого металу до абразивного зношування за рахунок додаткового легування міддю. і зменшення розміру зерна.

Ключові слова: наплавлення, зношування закріпленим абразивом, Fe–C–Cr–B–Ti сплав, зварювання самозахисним порошковим дротом, екзотермічне додавання.