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RESEARCH

Effect of Exothermic Addition (CuO - Al) on the Structure, Mechanical Properties and Abrasive Wear Resistance of the Deposited Metal During Self-Shielded Flux-Cored Arc Welding

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A B S T R A C T

The microstructure evolution, mechanical properties, and tribological properties of deposited metal Fe-C-Cr-Ti-B alloy by self-shielded flux-cored wire electrode (FCAW-S) with the introduction of exothermic addition and without it are investigated. Experimental studies showed that the introduction of CuO - Al exothermic addition in the composition of the wire core filler reduced the grain size of the deposited metal. Furthermore, X-ray diffraction analyses show that the boride layer contained FeB, Fe_2B, and Ti(C, N) phases. Depth-sensing indentation was used to determine hard phase properties (hardness, Young's modulus and plasticity coefficient). It was shown that introduction of CuO –Al exothermic addition in the core filer increased the mechanical properties of deposited metal. The latter can be explained by the grain size decrease, as well as a change in the phase composition of the deposited metal due to additional copper alloying. This transformation is accompanied by an increase in hardness and in the Young's modulus. Tribological tests showed the effectiveness of introduction of the exothermic addition CuO –Al into the filler core for increasing the wear resistance under conditions of 3-body abrasive particle wear.

1. INTRODUCTION

Wearing has a great influence on the efficient work of the equipment used in an open cut mining and therefore it's necessary to reduce it. The most dominant type of wear is abrasive wear [1-3]. Abrasive wear is a particularly important problem for the mining industry, where machines and machine parts are heavily scratched by abrasives such as minerals and earth.

In order to increase the service life of mining equipment and tools, design technological and operational methods are used. When designing the parts to be strengthened, pay special attention to the rational choice of materials and coatings [4-7], study of temperature distribution [8,9] and stresses in layered bodies, including bodies with defects [10-12] theoretical and experimental studies of wear processes [13,14] and tests taking into account the action of corrosive environment [15-17]. Technological methods provide the necessary accuracy of manufacturing parts, manufacturing errors of which lead to an increase in stress levels and cause uneven operation of the cutting elements of drill bits [18,19] and rational modes of surfacing [20,21]. Operational methods involve the use of vibration protection to improve the operating conditions of the tool [22-24].

Hardfacing techniques are employed mainly to extend or improve the service life of engineering equipment components [25,26]. One of the most common techniques to increase the wear resistance of the layer is self-shielded flux-cored wire welding (FCAW-S) [27-30]. Advantages of FCAW-S hardfacing include higher productivity, high quality of the deposited metal, the possibility of achieving a high degree of deposited metal alloying, high deposition rate, arc visibility, high resistance to pollutants, which can cause cracking [31].

Fe–B–C system flux-cored wire electrode hardfacing technology is used in different industry branches for equipment worn parts reinforcement [32-36]. However, are becoming more widespread by Fe-Cr-B-C and Fe-Ti-Cr-B-C system alloys, which have the best mechanical properties and wear resistance [8,37-41]. Moreover, these borides are based on the triple alloying system Fe-C-B, allowing to reduce quantity of more expensive, but more wide-spread alloying elements, comprising strengthening phase, such as Cr, Mo, V.

Yoo et all [42] analyzing an abrasive wear of boride steels came to conclusion that alloys with low content of boron (less than 0,6%) had higher wear resistance compared to metals with high content of boron (exceeding 1%). Abrasive wear reduction of steels comprising more content of boron (more than 1%) by FeB fragile phase formation and small quantity of residual austenite [42,43]. While steels with low content of boron are characterized with greater wear resistance connected with austenite availability in the matrix structure.

Alloying of Fe-Cr-C-B system by copper generates considerable interest. As known copper is hardly soluble in $Fe_2(B,C)$ and Fe(B,C) phases. It changes micro hardness and crack toughness coefficient of deposited metal very slightly [44].

Improving productivity and energy efficiency is one of the main challenges for developers of welding and surfacing filler materials. One of the promising methods for increasing energy efficiency (reducing energy consumption) and increasing the productivity of FCAW-S is the introduction of an exothermic addition into the core filler of a flux-cored wire electrode [45-49]. Recent studies of the author have shown the effectiveness of the desired copper content provision due to introduction of exothermic addition CuO - Al [48,50]. Copper transfers to deposited metal due to the reaction behavior (Eq. 1 [48]) recovery from monovalent copper oxide (CuO).

$$2 \cdot CuO + {}^{4}\!/_{3} \cdot Al = {}^{2}\!/_{3} \cdot Al_2O_3 + 2 \cdot Cu \qquad (1)$$

Available information suggests that the abrasive wear resistance of materials depends on factors like microstructure (their size and content), and mechanical properties of materials [51,52] . The most important parameters influencing wear protection performance are parameters relating to the micromechanical properties of the hard phases, such as hardness, Young's modulus, and fracture toughness [53].

Some authors emphasise, that the total number of reinforcing phase in the alloy not so important, as their morphology [54,55]. So Tan et all [56] inform that if the distance between the carbides is relatively large, the abrasive particles wear out the relatively soft matrix, stripping the reinforcing phase (carbides, borides). In this case, the wear intensity indicator can be an indicator of average distance between the borides [57], namely the size of the dendrites.

The aim of the study is to investigate the effect of the introduce of exothermic addition CuO - Al in the core filler of the flux-cored wire electrode and alloying of copper the deposited metal on the structure, phases formed, mechanical properties and abrasive with 3-body abrasive wear resistance.

2. METHODOLOGY AND MATERIALS

2.1 Hardfacing process

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 (St3ps) with dimensions 10x100x200 mm on reverse polarity by A-874 automatic machine. The chemical composition and mechanical properties of S235JRG1 EN 10025-94 as stated by the manufacturer are shown in Table 1 and Table 2.

Table 1. Chemical composition of the S235JRG2 EN 10025-94 steel in % wt.

C	Mn	Si	N	S	P
0,17	1,55	<0,55	0,009	0,045	0,045

Table 2. Mechanical properties of the S235JRG1 EN 10025-94 steel.

Hardness HV	Impact strength K [kJ/m^2]	Ultimate elongation A_5 [%]	Tensile strength Rm [MPa]
140	≥27	≥24	340

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) [45,47], as well as for low solution of the deposited metal with the base metal and providing welded bead optimal shape [48,49]. Thus, hardfacing was performed by FCAW-S according to the parameters are shown in Table 3.

Table 3. Welding parameters used in hardfacing process.

Parameters	Values
Wire feed speed WFS [m/min]	1.85
Arc welding voltage U_a [V]	28
Travel speed TS [m/min]	0.3
Contact tip to work distance CTWD [mm]	35
Pola-rity	DCRP
Preheating T_p, [°C]	250…300

Average values of welding current when surfacing with flux-cored wire FCAW-S-140Cr15Si1MnBTi was 410 Amp, while when surfacing with experimental flux-cored wire FCAW-S-110Cr4Cu5TiVBAl - 320 Amp.

The coefficient wire filling (filling factor) of the flux-cored wire electrode is 0.34-0.35 [45,50]. Core filler compositions of experimental FCAW-S are shown in Table 4.

Table 4. Core filler compositions of FCAW-S (diameter 4 mm), [wt.%].

The name of the component		Components content in the core filler [wt.%]
Gas-slag-forming components	Fluorite concentrate GOST 4421-73	11
	Rutile concentrate GOST 22938-78	7
	Calcium carbonate GOST 8252-79	4
Alloying and deoxidizers	Ferromanganese FMn-88A GOST 4755-91	5
	Ferrosilicon FeS-92 GOST 1415-78	4
	Ferrovanadium FVd-40 GOST 27130-94	2
	Metal Chrome X99 GOST 5905-79	10,4
	Titanium powder PTM-3 TU 14-22-57-92	5
Graphite is silver		5,3
Boron carbide B_4C		9,6
Oxide of copper powder-like GOST 16539 79		25,6
Aluminium powder PA1 GOST 6058-73		6,4
Iron powder PZWR-1 GOST 9849-86		6,7

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). Preheating and associated heating were made to eliminate the formation of defects in the weld metal during the deposition of each weld bead. Preheating was made in the electric chamber furnace. At that the required temperature during the hardfacing process and each subsequent layer deposition was provided with associated heating using a gas burner. The temperature of the preheating and associated heating was monitored by pyrometer.

Samples for microstructure analysis, mechanical properties investigation and three-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.

2.2 Mechanical properties measurements by depth-sensing indentation tests

The indentation became a simple and reliable method for determination of the complex of mechanical properties of materials [58] and coatings [59].

The physical-mechanical properties of the samples surface were investigated by the depth-sensing indentation (instrumented indentation) method using the universal micro/nano-hardness tester "Micron-Gamma" [60]. Depth-sensing indentation tests allows to measure the hardness H_{IT}, reduced elastic modulus E_{IT} and plasticity coefficient δ [61] of the sample's phases. The measurements were done using a diamond Berkovich indenter. Indenter penetration depth against the specimen surface is recorded with an accuracy of 5 nm. The measurements were carried out with maximum load on the indenter 50 g and a loading rate 5 mN/s. Obtained results were correlated to the procedure described in [62]. 7 indentation tests were done for each phase with a distance 50 µm between indents to obtain mean values and standard deviation.

2.3 Characterization

The average chemical composition of the alloys was detrmined by atomic absorption spectroscopy method using Spectrolab LAVFC01A device. The alloys were examined by light optical microscope Neophot. Quantitative metallography was carried out with structural analyzer Epiquant. X - ray diffraction analysis was done to identify the existing phases in produced samples on an X - ray diffractometer ДРОН-УМ-1 with CuKα source. The phase transformations were investigated by means of differential thermal analysis (DTA).

2.4 Abrasive wear test

Principal scheme of the abrasion tester for three-body abrasive wear test is presented in Fig. 1. The abrasive is introduced between the test specimen and a rotating wheel. Test specimen is pressed against the rotating wheel at a specified force by means of a lever arm while a controlled flow of grit abrades tested surface. Wheel rotation is such that its contact face moves in the direction of the sand flow. Dried quartz sand (humidity should not exceed 0.16%) was continuously fed to the contact areas of the rubber disk and the sample. The speed of rotation of the mold was 25 (m / s), and the force of its pressing to the specimen 2.4 (kN). Such force was chosen in order to simulate experimental conditions closer to the real dragline teeth operating conditions. Specimens are weighed before and after the test and the loss in mass recorded.

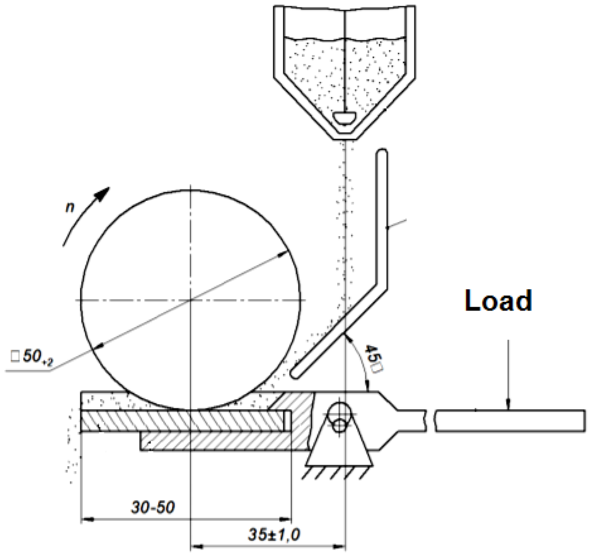


Fig. 1. Abrasion tester principle.

Conditions of three-body abrasive wear test are presented in Table 5.

Table 5. Conditions of 3-body abrasive wear test.

Parameters	Values
Size specimen body, [mm]	30×30×*h*,
Wheel diameter, [mm]	48...50
Wheel width, [mm]	15 ± 0,1
The rate of revolution, [rpm]	4
Test load, [N]	2400
Sand flow rate, [g/min]	300...400
Average size of sand particles, [µm]	200 ... 1000
Time, [min]	60
Lineal Abrasion, [m]	18,75

Wearing was estimated based on the samples loss of mass with an accuracy of $\pm 2 \cdot 10^{-4}$ g on analytical balance of KERN ABJ 220 4M brand.

Equations 2 and 3 are used for finding wear volume (WV), specific wear rate (SVR) and relative wear resistance (ψ), respectively.

Specific wear rates (in mm^3/Nm) of the specimen was calculated using Eq.1 [63]:

$$SVR = {WV}/{N \cdot L} \qquad (2)$$

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

The tested material relative wear resistance ψ_{abr} is calculated using the Eq. 2 [64,65]:

$$\phi_{abr} = {Wh_{pz}}/{Wh_z} \qquad (3)$$

where
Wh_{PZ} – mean weight loss of etalon sample, g;
Wh_Z – mean weight loss of samples of tested material, g.

3. RESULTS AND DISCUSSION

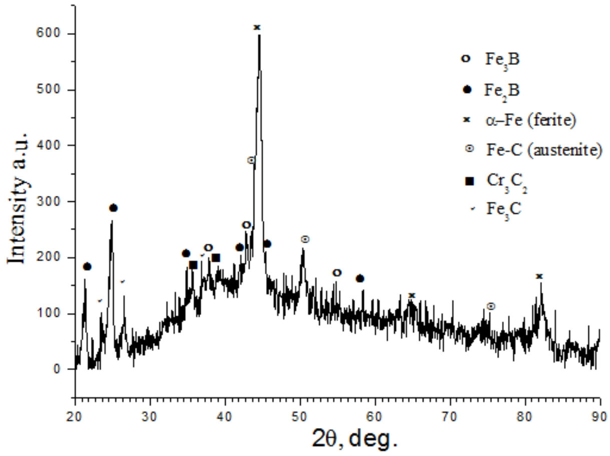
3.1. The results

The results obtained on the study of the chemical composition of the hardfaced deposited metal by widely used flux-cored wire electrode and experimental FCAW-S are shown in Table 6.

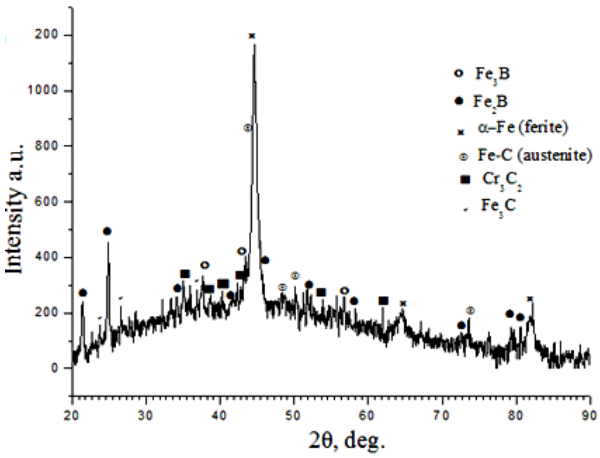
Table 6. Chemical composition (wt.%) of hardfacing layers in 3-th layers.

Content of alloying element in metal deposit, wt.%	Sample no.	
	FCAW-S-140Cr15Si1MnBTi	FCAW-S-110Cr4Cu5TiVBAl
C	1,42	1,08
B	0,22	0,45
Cu	0,15	5,2
Cr	12,72	3,51
V	0,13	0,26
Ti	0,43	1,49
Mn	1,39	1,18
Si	1,8	1,23
S	0,037	0,031
P	0,016	0,017
N	0,034	0,046
Fe	Bal	

In order to determine the effect of adding copper to the alloy of the Fe-Ti-Cr-B-C doping system on the microstructure and phase composition of the alloy, X-ray diffraction XRD analysis was performed. The results of XRD-analysis of the deposited metal hardfacing by flux-cored wire electrode FCAW-S 140Cr15Si1MnBTi, and flux-cored wire electrode with exothermic addition FCAW-S 110Cr4Cu5Ti1MnVB are shown in Fig. 2.



a)

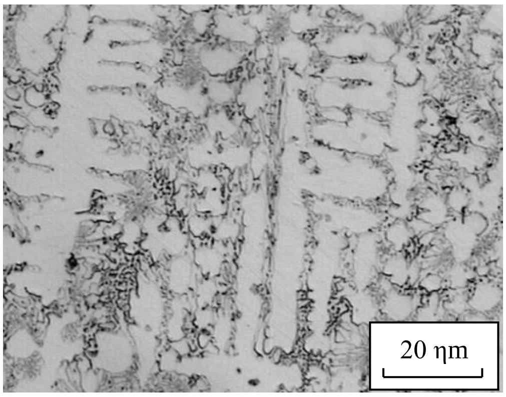


b)

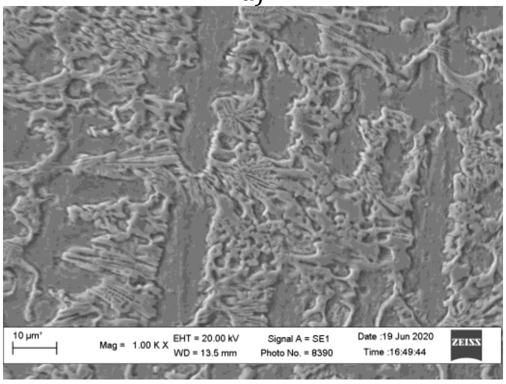
Fig. 2. XRD pattern of deposited metal in 3 layers: a) FCAW-S-140Cr15Si1MnBTi; b) FCAW-S-110Cr4Cu 5TiVBAl with exothermic addition CuO - Al.

According to Fig. 2 the phase of the alloy mainly consists of α Fe, γ Fe, borides of Fe_3B and Fe_2B, as well as carbides of chromium (Cr_3C_2) and cementite (Fe_3C). Titanium carbides can also be identified in the deposited metal (not shown in the diagrams) in the deposited metal hardfacing by FCAW-S-110Cr4Cu5TiVBAl.

The microstructures of the deposited metal made using an optical microscope (OM) and a scanning electron microscope (SEM) are shown in Fig. 3 and Fig. 4.

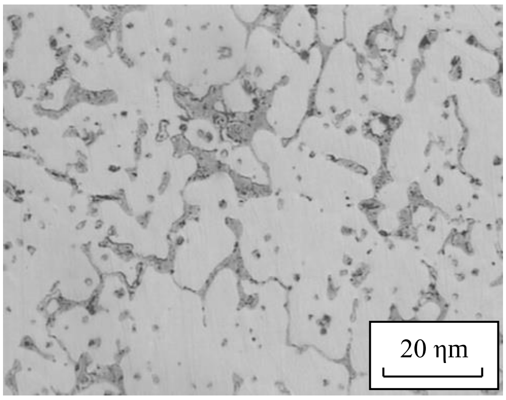


a)

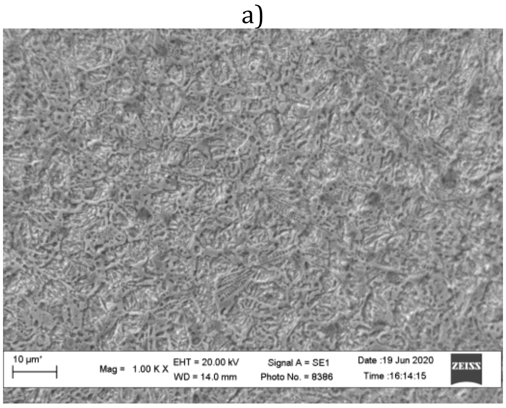


b)

Fig. 3. The metallographic structure x500 (a) and SEM images of the microstructures x1000 (b) metal hardfacing by FCAW-S-140Cr15Si1TiMnB.



a)



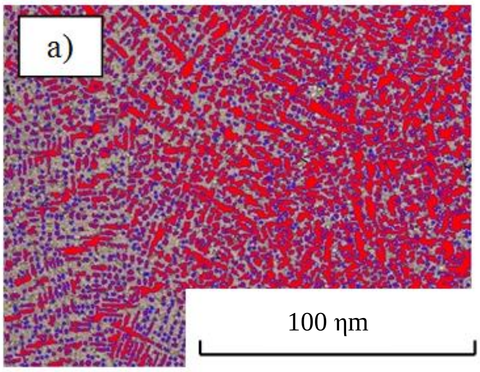
b)

Fig. 4. The metallographic structure x500 (a) and SEM images of the microstructures x1000 (b) of deposited metal hardfacing FCAW-S-110Cr4Cu5Ti1VB.

Microstructure of the deposited metal consists of matrix and borides (Fe_2B, Fe_3B), which form a three-dimensional chain surrounding the matrix. Structure of alloys consists of a two-phase feritic-austenitic phases, and a eutectic containing borides (Fe_2B, $Fe_3(B, C)$) with individual titanium carbonitrides.

3.2 Dendritic grain size of deposited metal

To analyze the effect of introducing an exothermic addition into the filler core, photographs of the microstructure made by an optical microscope were used. The results are shown in Fig. 5.



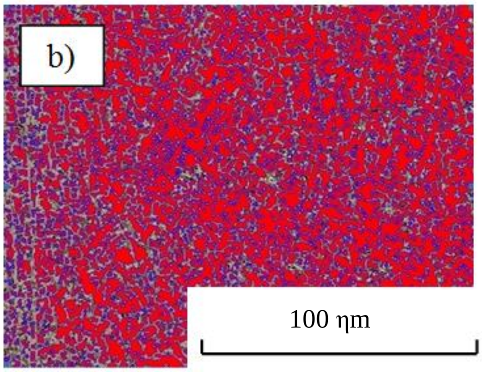


Fig. 5. Analysis of grain size deposited metal hardfacing: a) FCAW-S-140Cr15Si1TiMnB; b) FCAW-S 110Cr4Cu5Ti1VB.

The grain morphology parameters of the deposited metals were obtained according to the results of studies of the microstructure (Fig. 5) are presented in Table 7.

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, and the average perimeter from 63.9 µm to 56.1 µm. The minimum values of the perimeter and length of dendrites were similar. However, according to the obtained data (Table 7) the average grain area values (241.5 μm² vs. 331.6 μm²) and the values of the maximum perimeter and length of dendrites in the deposited metal applied during FCAW-S with the introduction of exothermic additions were higher.

Table 7. The results of the analysis of grain size determination.

Sample	Parameter	Number of analysed objects	Average value	Min. value	Max. value
140Cr15Si1MnBTi	Area, μm²	1488	241,5	3,3	166786
	Perimeter, μm		63,9	7,2	16106,8
	Length, μm		15,3	2,6	719,8
110Cr4Cu5TiVBAl	Area, μm²	1784	331,6	3,3	421381
	Perimeter, μm		56,1	7,3	21742
	Length, μm		12,9	2,6	988,5

Summarizing the results discussion concerning the influence of exothermic additions introduction to the grain morphology of deposited metal we can conclude its positive influence. On the one hand the positive role of exothermic additive introduction can be explained by the cooling rate decrease due to the welding current decrease [50]. On the other hand - the formation of a large number of small non-metallic inclusions (NMI), which played the role of grain refiner/modifying agents.

3.3. Mechanical properties

Typical load-displacement diagram recorded during depth-sensing indentation test of studied materials shown in the Fig. 6.

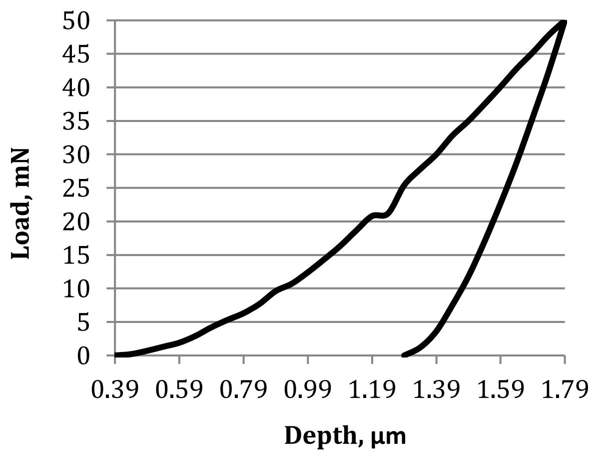


Fig. 6. Typical load vs. depth curve recorded during depth-sensing indentation test.

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 8.

Table 8. Mechanical properties determined by the depth-sensing indentation test.

Filler material	Instru-mented hardness H_{IT}, GPa	Elastic modulus E_{IT}, GPa	Plasticity coefficient δ
FCAW-S-140Cr15Si1MnBTi	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

Comparative diagrams of the mechanical properties of studied samples obtained by depth-sensing indentation test are presented in Fig. 7 (instrumented hardness (Fig. 7 (a)), modulus of elasticity (Fig. 7 (b)) and plasticity coefficient (Fig. 7 (c)).

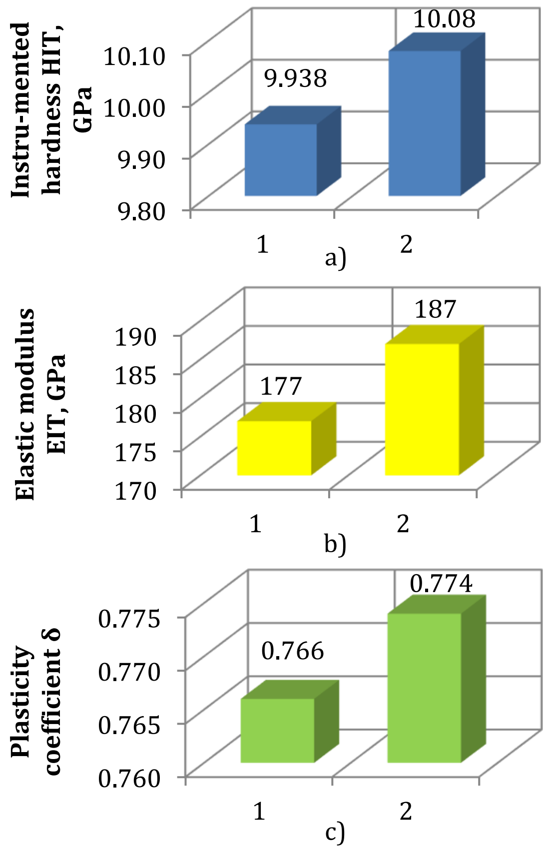


Fig. 7. Comparative diagrams of mechanical properties of welded metals FCAW-S-140Cr15S1MnBTi and experimental FCAW-S-110Cr4Cu5Ti1B: a) instrumented indentation (H_{IT}); b) modulus of elasticity (E_{IT}); c) plasticity coefficient (δ).

The introduction of the exothermic additive CuO-Al had a positive effect on the mechanical properties of the deposited layer, increasing the average values of microhardness, modulus of elasticity and ductility. The increase in the hardness can be explained primarily by the strengthening as per the Hall-Petch mechanism associated with the structure dispersion [66]. In this case, the smaller the grain size is, the stronger the material. The second factor is the second phase content in the matrix. This distribution characteristic is favorable for the grain bound fixing, which can increase the strength of steel. The positive effect on phase sizes reducing during alloying of Fe–B–C alloys with such elements as Cu, Ni and Mn is confirmed by Sukhova V.V. [44].

The positive effect on the elasticity modulus in case of exothermic addition introduction to the core filler can be explained by the increasing of ferrite in the matrix. The results of Leslie [67], Münstermann, S. and Bleck W. [68] showed that austenite has lower modulus of elasticity than ferrite. As mentioned above, according to the XRD patterns, the intensity of ferrite phase of the sample of metal deposited by the flux-cored wire electrode after exothermic addition introduction increases.

3.4. Wear resistance

Some tests for the deposited metal abrasive wearing were performed applying standard and experimental FCAW-S to compare the abrasive wear resistance. Additional tests were performed on the abrasive wear of the steel sample St. 40 in the annealed state to calculate the relative wear resistance. The test results are given in Table 9 and in Fig. 8.

Table 9. Result of the 3-body abrasive wear test.

Sample	Wear mass loss, [g]	Relative wear resistance (St.40)	Specific wear rates SVR, [mm³/Nm]
St.40 annealing	0,679	1	1,0031
140Cr15Si1 MnBTi	0,0867	7,8	0,1287
110Cr4Cu5 Ti1MnVB	0,0533	12,68	0,0791

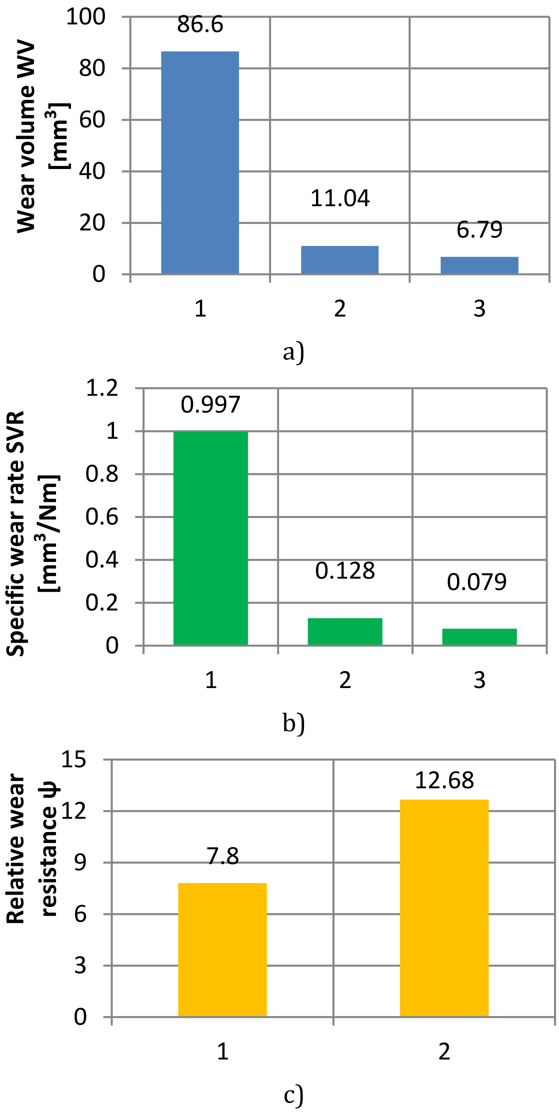


Fig. 8. Corresponding graphs of results of the 3-body abrasive wear test (1 – St.40; 2 - 140Cr15Si1MnBTi; 3 - 110Cr4Cu5Ti1MnVB), where: a) wear volume (WV); б) specific wear rates (SVR); c) relative wear resistance (φ).

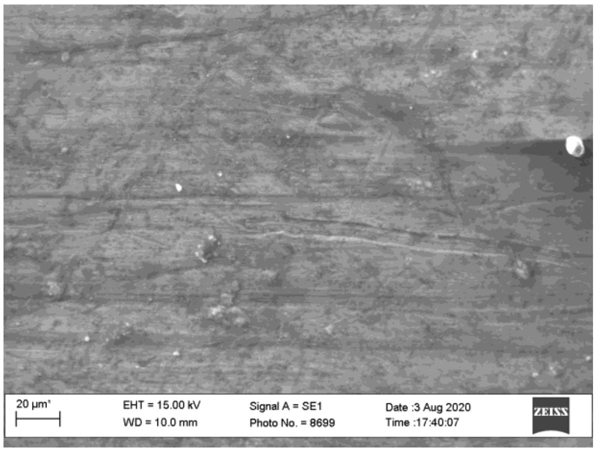


Fig. 9. SEM micrographs of worn surfaces tested for 3-body abrasive wear test deposited metal by FCAW-S 140Cr15Si1MnBTi at magnification x5000 (b).

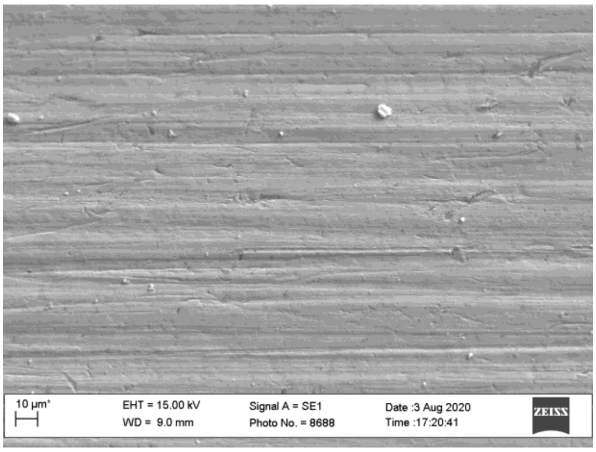


Fig. 10. SEM micrographs of worn surfaces tested for 3-body abrasive wear test deposited metal by FCAW-S 110Cr4Cu5Ti1MnVB at magnification x5000 (b).

Morphological features of the friction surfaces due to wear of the 3-body abrasive metal, hardfacing by FCAW-S-140Cr15Si1MnBTi and FCAW-S-110Cr4Cu5Ti1MnVB are showed in Fig. 9 and Fig. 10.

According to the samples loss of mass due to the 3-body abrasive wear of the deposited metal, it was found that an introduction of exothermic addition CuO - Al increases the wear resistance of deposited metal (see Fig. 8). After 3-body abrasive wear the weight loss of the sample, hardfaced with flux-cored wire electrode FCAW - S - 140Cr15Si1MnBTi (without exothermic addition), had a value of 0.0867 g. The relative wear resistance (WR) was SVR = 0.1278 [mm^3/Nm] and relative wear resistance φ=7,8. Whereas in case of using the experimental flux-cored wire electrode FCAW-S 110Cr4Cu5Ti1MnVB with the introduction of an exothermic addition CuO - Al in the core filler, the weight loss was 0.0533 g. At that the wear resistance was SVR = 0.0786 [mm^3/Nm] and relative wear resistance φ=12,68. Thus, the wear resistance increased 1.58 times.

The physical interactions between the abrasive particles and the abraded surface are studied in order to clarify the mechanisms of deformation and wear and can be divided into four types: microploughing, microcutting, microfatigue and microcracking [57]. The main mechanism of wear of the strengthening layer of the welded FCAW-S 140Cr15Si1MnBTi is microcutting and microfatigue (microcracking). The chipping of solid borides (Fe_2B and FeB) becomes the main mechanism. The main disadvantage of the layers deposited by means of standard FCAW-S 140Cr15Si1MnBTi is the dendritic structure with needle-like morphology. The sharp peaks of the solid phase act as stress concentrators, which cause due to considerable loads cracking of the deposited metal and its further chipping. The first can be caused by the growth and combination of microcracks caused by fatigue of the material, leading to the loss of material fragments [69].

However, the deposited metal made of the flux-cored wire electrode FCAW-S-110Cr4Cu5Ti1VBAl had greater resistance to abrasive wear. It's confirmed by less weight loss (0.1122 g). The greater wear resistance of the deposited metal applied by the experimental FCAW-S can be explained by the structure crushing (reducing the grain) [65,70,71] and increasing more elastic and plastic ferrite phase in the matrix, which has a positive effect on mechanical characteristics (microhardness, elasticity and ductility) [65]. The increase in wear resistance could be explained by the presence of a much smaller boride needles, reducing the stresses concentration in the boride. At the same time, greater values of the modulus of elasticity increase the wear resistance. The latter is provided by an austenitic-ferritic matrix. Increase hardness can also be attributed to the increase in the amount of ferrite phase with as the ferrite phase is harder than austenite phase [72]. The increase in wear resistance can be explained by the presence of a great content of free ferrite reducing the intensity of accumulated dislocations and the sensitivity of the deposited metal to stress concentration [73]. Higher wear resistance is attributed to resistance to plastic flow leading to formation of humps and the formation of surface fatigue cracks [74].

4. 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 three-body abrasive particles were performed.

2. Introduction of exothermal addition CuO-Al to the core filler alloyed the deposited metal by copper and increased the content of ferrite and austenite phase in the matrix. It's confirmed by more intensity at XRD patterns. Moreover, exothermal addition introducing caused the grain fragmentation of deposited metal.

3. Studies showed a positive effect of exothermic addition CuO-Al on mechanical properties. However, the microhardness and plasticity coefficient increasing was insignificant, while the average value of the elasticity modulus increasing was more significant (from 176,987 GPa to 186,989 GPa).

4. 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.

5. Investigations of flux-cored wires electrode without an exothermic addition and with the introduction of an exothermic additive CuO-Al into the composition of the filler core with three bodies of abrasive wear were carried out. Research has shown an increase in abrasion resistance by 1.58 times. The increase in resistance to abrasive wear was attributed to an increase in mechanical properties, due to an increase in the ferrite phase and its morphology, as well as a decrease in grain size.

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