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Development of a wear-resistant flux cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system for deposit welding of mining equipment parts

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Abstract. The effect of introduction of cobalt in the charge of the flux cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system operating under abrasive and abrasive-shock loads is studied. In the laboratory conditions samples of flux cored wires were made, deposition was performed, the effect of cobalt on the hardness and the degree of wear was evaluated, metallographic studies were carried out. The influence of cobalt introduced into the charge of the flux cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system on the structure, nature of nonmetallic inclusions, hardness and wear resistance of the weld metal was studied. In the laboratory conditions samples flux cored wire were made using appropriate powdered materials. As a carbon-fluorine-containing material dust from gas cleaning units of aluminum production was used. In the course of the study the chemical composition of the weld metal was determined, metallographic analysis was performed, mechanical properties were determined. As a result of the metallographic analysis the size of the former austenite grain, martensite dispersion in the structure of the weld metal, the level of contamination with its nonmetallic inclusions were established.

1. Introduction

Repair of mining equipment requires significant costs for its replacement or restoration [1]. One of the most effective technologies for hardening and restoring parts is arc welding by flux cored wire [2]. Therefore, the development of materials and the use of innovative recovery technologies that significantly increase the wear resistance of products is today an urgent task. For this purpose, the development and manufacture of special surfacing flux cored wires is being carried out [3-16]. Due to optimally selected chemical composition of flux cored wires, the welded coatings have high hardness, as well as abrasive and shock abrasive wear resistance. Welding wires of Fe-C-Si-Mn-Cr-Ni-Mo systems – type A and B according to the classification of MIS are widely used for surfacing abrasive-wear parts [17]. At present such flux cored wires of various foreign productions are widely applied in our country.

2. Methods of research

The influence of cobalt introduced into the burden of the flux-cored wire of the Fe-C-Si-Mn-Cr-Ni-Mo-V system in the manufacture of wire test samples, the degree of wear of the samples and the hardness of the deposited layer. The production of a flux-cored wire and its surfacing for the preparation of samples was carried out according to the technology given in [18, 19].

The wire was manufactured on a laboratory machine. Diameter of the wire is 5 mm, the cover is made from a strip St3. As the filler the appropriate powdered materials were used: iron powder PZhV1 according to GOST (Russian State Standards) 9849-86, ferrosilicon powder FS 75 according to GOST1415-93, high-carbon ferrochromium powder FKh900A according to GOST 4757-91, carbon ferromanganese powder 78 FMn(A) according to GOST 4755-91, nickel powder PNA-1L5 according to GOST 9722-97, ferromolybdenum powder FMo60 according to GOST 4759-91, ferrovanadium powder FV50U 0.6 according to GOST 27130-94, cobalt powder PK-1U according to GOST 9721-79, and as a carbon-containing component dust from gas-cleaning units at aluminum production was used with the following component composition, wt%: Al_2O_3 = 21-46.23; F = 18-27; Na_2O = 8-15; K_2O = 0.4-6; CaO = 0.7-2.3; Si_2O = 0.5-2.48; Fe_2O_3 = 2.1-3.27; C_{tot} = 12.5-30.2; MnO = 0.07-0.9; MgO = 0.06-0.9; S = 0.09-0.19; P = 0.1-0.18.

The hardness was measured using a MET-UD hardness tester. Five hardness measurements were made on the surface of each sample. Table 1 shows the averaged values for the hardness of the weld metal averaged over five measurements. Wear-resistance tests were carried out on the machine 2070 SMT-1 as follows. Samples were weighed on scales, with the possibility of measuring masses up to 10^{-4} g. After recording the weight of samples, a wear-resistance test was carried out by rotating the disc welded by tungsten alloys on a flat surface of the weld metal for 6 hours with the following conditions: load – 30 mA, rotation speed – 20 rpm. After the wear-resistance tests, the samples were weighed and the difference between the initial and final weight was determined, and also the number of disk revolutions of the installation 2070 CMT-1 was recorded. Wear-resistance was determined on the basis of a decrease in the sample weight per one revolution of the disk. The results of the tests, hardness measurements and chemical analysis of samples are given in table 1.

Table 1. Chemical composition, wear and hardness of deposited metal.

Sample number	Mass fraction of elements, %								Hardness of samples HRC	Wear of samples g/r*10^{-4}
	C	Si	Mn	Cr	Mo	Ni	V	Co		
1	0.24	0.19	0.93	1.83	0.69	0.14	0.60	-	41	0.37
2	0.25	0.27	0.96	1.65	0.68	0.33	0.60	-	40	0.358
3	0.25	0.28	0.93	1.67	0.57	0.54	0.58	-	40	0.359
4	0.29	0.15	0.92	1.65	0.60	0.65	0.59	-	41	0.449
5	0.23	0.12	0.85	1.45	0.53	0.51	0.68	0.08	25	1.65
6	0.21	0.23	0.89	1.45	0.54	0.55	0.54	0.03	21	1.15
7	0.17	0.18	0.85	1.40	0.52	0.54	0.63	0.05	21	1.11
8	0.17	0.28	0.91	1.32	0.45	0.46	0.59	0.06	21	1.12

The metallographic analysis of the samples was carried out using OLYMPUS GX-51 optical microscope in the bright field with the magnification range × 100-1000. An alcoholic solution of nitric acid was used as a reagent for etching the samples surface. Investigation of longitudinal samples of the welded layer for the presence of nonmetallic inclusions was made according to GOST 1778-70 with magnification × 100. The value of the former austenite grain was determined according to GOST 5639-82 with magnification × 100. The size of the martensite needles was determined according to GOST 8233-56 with magnification × 1000.

3. Results and discussion

Metallographic analysis showed that the microstructure of the deposited layer with a carbon content of 0.24-0.29% (samples No. 1-4) is uniform, thin branches of dendrites are observed. The microstructure represents a fine-needle and medium-needle martensite (point No. 3-6) in the former austenite grains, along the boundaries of which thin δ-ferrite interlayers are located, and a small amount of residual austenite in the form of separate islets. The size of the martensite needles in the structure of the examined samples is in the range of 2-10 µm (table 2, figure 1).

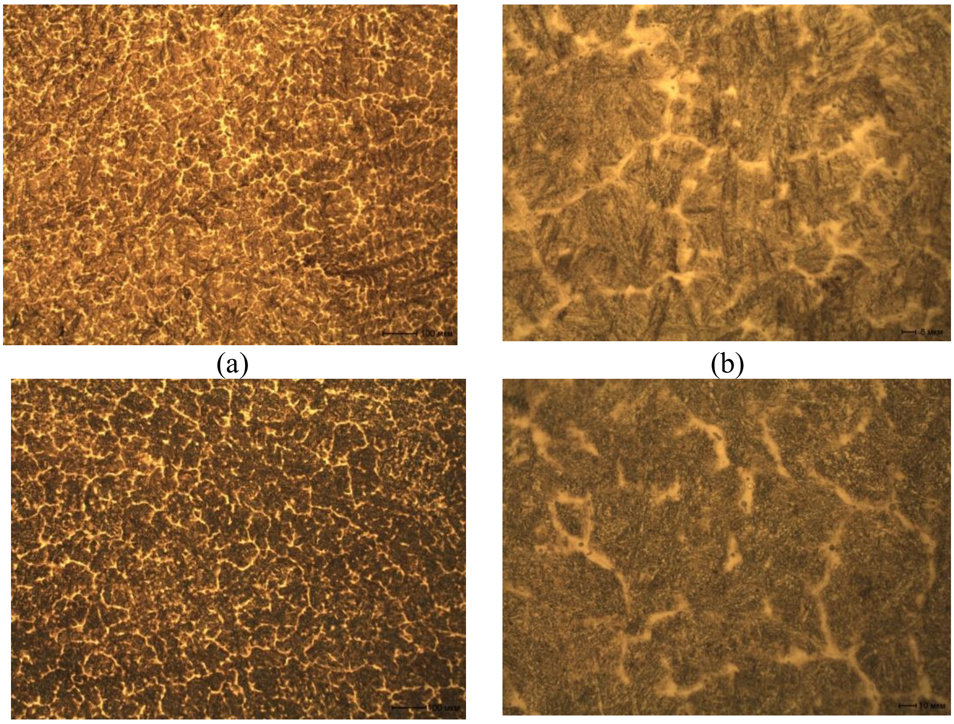
In the microstructure of sample No. 1 there is medium-needle martensite (score No. 5, 6) (figure 1a, b). The value of primary grains of austenite on the grain scale corresponds to No. 5 and No. 6.

Table 2. Characteristics of nonmetallic inclusions and samples structure.

Sample number	Contamination with non-metallic inclusions, points		Austenite grain size, point	Size of martensite needles, μm
	Silicates nondeforming (brittle)	Spot oxides		
1	2b, 2a, 3a	1a	5, 6	7-10
2	1b, 2b, 3a	1a	5, 6	4-8
3	2b, 3a	1 a	5, 6	5-8
4	2b, 3a (1b)	1 a	6, 5	2-5
5	1b, 2b, 3a	1 a	6, 5	2-5
6	1b, 2b, 2a	1 a, 2a	6	2-4
7	1b, 2b, 3a	1 a	6	2-5
8	1b, 2b, 3a	1 a	6	2-4

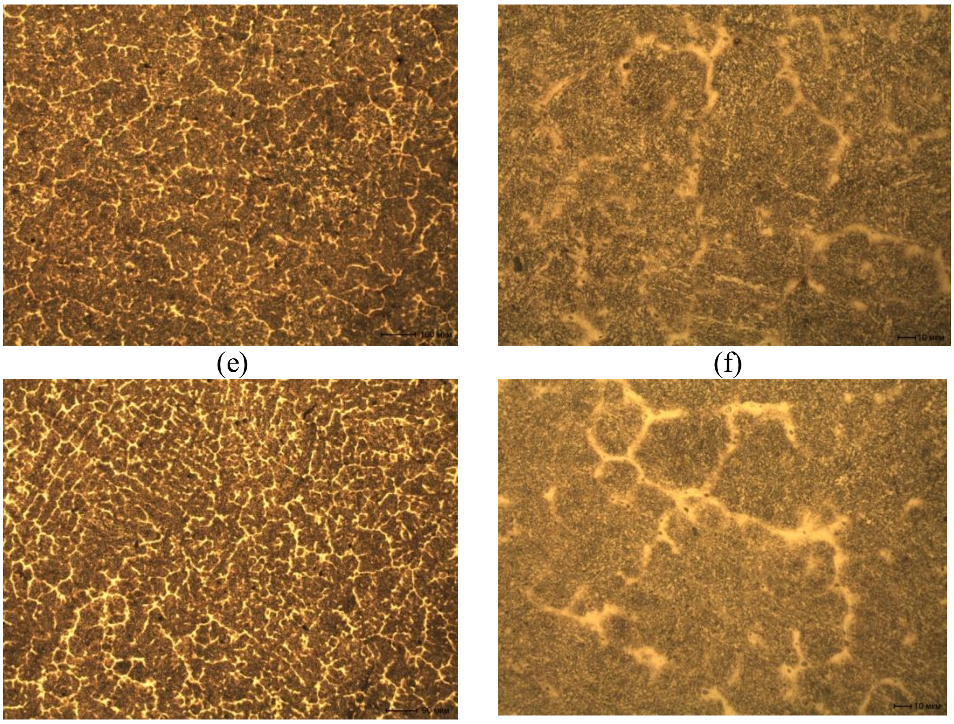
When the nickel content is increased to 0.33-0.54% the austenite grain size remains unchanged. In the microstructure of samples No. 2 and 3 medium-needle martensite (score No. 5) is also present, however, in some of its zones fine-grained martensite is observed (point No. 3) (figure 1 c-f, Table 2).

An increase in the nickel content to 0.65% (sample No. 4) significantly crushes the martensite needles, and also reduces the size of the former austenite grain. In the microstructure of sample No. 4, fine-grained martensite (point No. 3) is observed formed within the boundaries of the former austenite grain, the value of which corresponds to No. 6 and No. 5 on the grain size scale (figure 1 g, h, table 2).



(a) (b)

(c) (d)



(e) (f)

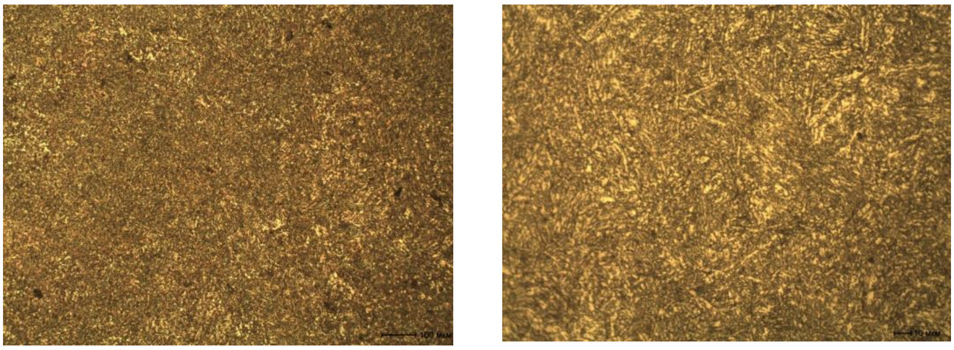
(g) (h)

Figure 1. Deposited layer microstructure of flux cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system with the improved composition (a, c, e, g × 100), (b, d, f, h × 500). a, b – sample No. 1; c, d – sample 2; e, f – sample No. 3; g, h – sample No. 4.

The introduction of cobalt into the deposited flux cored wire with simultaneous reduction of carbon content up to 0.17-0.23% (samples No. 5-8) provides a uniform structure with fine-needle martensite (score No. 3) in the former austenite grains, the residual austenite present in a small amount in the form of separate islands, and δ-ferrite in the form of thin interlayers along the boundaries of the primary austenite grains (figure 2).

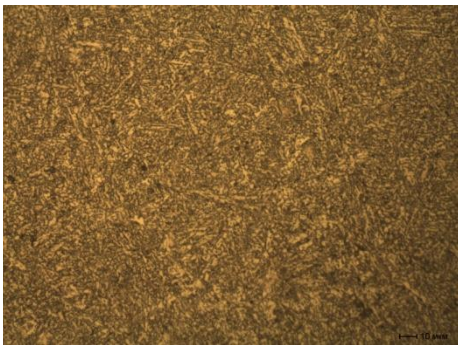
The size of martensite needles in the structure of the samples under study is in the range of 2-5 μm (table 2). The value of the former austenite grain corresponds to No. 6.

Thus, it was established that an increase in nickel content up to 0.65% in the weld steel as well as introduction of cobalt with simultaneous reduction of carbon content up to 0.17-0.23% helps to crush refine and reduce the size of the former austenite grain.

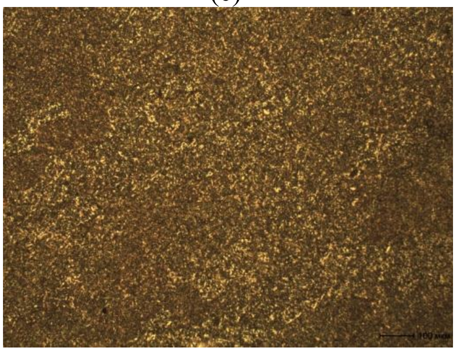


(a) (b)

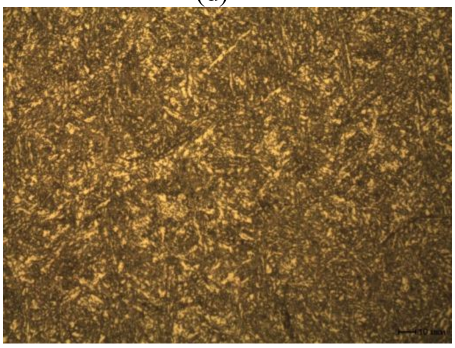
(c)



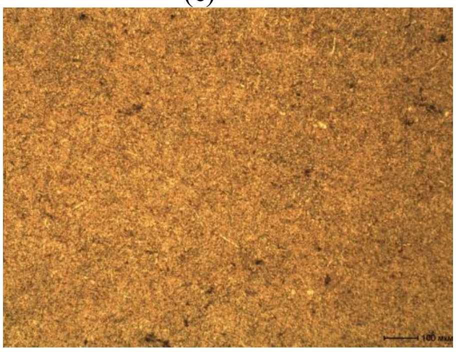
(d)



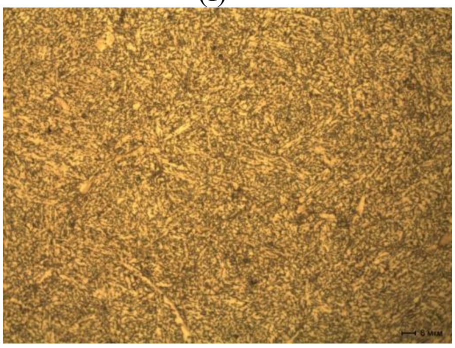
(e)



(f)



(g)



(h)

Figure 2. Deposited layer microstructure of flux cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system with cobalt (a, c, e, g × 100), (b, d, f, h × 500). a, b – sample No. 5; c, d – sample No. 6; e, f – sample No. 7; g, h – sample No. 8.

As a result of studying the nature of nonmetallic inclusions of the welded layer by the flux-cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system the contamination with oxide nonmetallic inclusions was noted (table 2).

It was established that the change in the degree of alloying of the flux-cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system has practically no effect on the contamination level with nonmetallic inclusions of the layer deposited by it.

The effect of chemical composition of the flux cored wire of Fe-C-Si-Mn-Cr-Ni-Mo-V system on the degree of wear and the hardness of the welded layer was estimated using multivariate correlation analysis, which allows the patterns of the change in the resultant index depending on the behavior of various factors described in [20, 21, 22] to be studied.

The factors that influence the examined indicator were determined for the analysis, and the most significant of them were selected (table 1). After that, the initial information was checked for reliability, uniformity, compliance with the law of normal distribution. Then a model of the factor system was constructed. Since the above systems have independent factor characteristics, the deterministic factor analysis is used.

The type of connection was determined using pair and partial correlation coefficients. It is revealed that the relationship has a rectilinear character, which is also confirmed by the determinism coefficient, which equals to 1 for the models of reduced factor systems.

The calculation of main connection indicators of the correlation analysis was carried out in stages. First, one factor was taken into account which has the most significant effect on the resultant index, then the second, third, etc. At each stage, the equation of connection and indicators were calculated, with the help of which its reliability is estimated.

Based on the results of the calculations we obtained dependencies, the adequacy of which was checked for actual values by the average error of approximation:

$$\bar{\varepsilon} = \frac{1}{m}\sum_{i=1}^{m}\left|\frac{Y_i - \tilde{Y}_i}{Y_i}\right| \cdot 100, \qquad (1)$$

where m – the number of observations; $\tilde{Y}_i$ is the calculated value of the resulting indicator; Y_i – the actual value of the resulting indicator.

As a result of the analysis, the following dependencies were obtained:

- hardness of the deposited metal when Co is added to the system Fe-C-Si-Mn-Cr-Ni-Mo-V:y=156.66*C+10.92*Si-6.94*Mn-7.51*Cr-75.67*Mo-28.10*Ni+129.45 *V-364.27*Co (approximation error 0.01%);
- wear resistance of the deposited metal when Co is added to the system Fe-C-Si-Mn-Cr-Ni-Mo-V:y=-0,000101*C+0,000052*Si-0,000126*Mn+0,000117* Cr+0,000413*Mo+0,000130*Ni-0,000583*V+0,002874*Co (approximation error 1.59 %);

The calculated values of the mean error of approximation show that the obtained dependences are adequate and they can be used to determine the resulting indicators.

4. Conclusions

1. It was established that an increase in nickel content up to 0.65% in the composition of deposited steel, as well as the introduction of cobalt, simultaneous with the reduction of carbon content up to 0.17-0.23% provides refinement of martensite needles and decrease the size of the former austenite grain.

2. Change in the chemical composition of the flux cored wire of the Fe-C-Si-Mn-Cr-Ni-Mo-V system practically does not affect the contamination level with nonmetallic inclusions of the layer deposited by it.

3. Based on the results of the multifactor correlation analysis the hardness of the deposited layer and its wear resistance were determined from the mass fraction of the elements in the composition of flux cored wires of Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system. The obtained dependences can be used to predict the hardness of the deposited layer and its wear resistance when the chemical composition of the weld metal changes.

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