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Study of the properties of flux cored wire of Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system for the strengthening of nodes and parts of equipment used in the mineral mining

A I Gusev, N A Kozyrev, A A Usoltsev, R E Kryukov and I V Osetkovsky

Siberian State Industrial University, 42 Kirova Street, Novokuznetsk, 654007, Russia

Email: kozyrev_na@mtsp.sibsiu.ru

Abstract. The effect of the introduction of vanadium and cobalt into the charge of the powder surfacing wire of Fe-C-Si-Mn-Cr-Mo-Ni system is studied. In the laboratory conditions, the samples of flux cored wires were produced. The surfacing made by the prepared wire was produced under the flux AN-26C, on the plates of steel St3 in 6 layers with the help of ASAW-1250 welding tractor. Reduction of carbon content in the deposited layer to 0.19-0.2% with simultaneous change in the content of chromium, nickel, molybdenum and other elements present in it contributes to the enlargement of the martensite needles and the increase in the size of the former austenite grain. The obtained dependences of hardness of the deposited layer and its wear resistance on the mass fraction of elements, included in the composition of powder wires of the proposed system, can be used to predict the hardness of the welded layer and its wear resistance under different operating conditions for mining equipment and coal mining equipment.

1. Introduction

The mechanisms of machines of mining equipment, which experience abrasive and impact wear during operation, fail prematurely. Wear of their working surfaces necessitates restoration. Therefore, the development of materials that significantly increase the wear resistance of such parts and the use of technology for their recovery is an important task. The most promising is the use of surfacing by flux cored wire on the wear surfaces of parts. For these purposes in our country and abroad the development and manufacture of special surfacing powder wires is being carried out [1 - 14]. Thanks to the optimal selected method of alloying the welded coatings have high values of hardness, abrasive and shock abrasive wear resistance.

Welding wires of Fe-C-Si-Mn-Cr-Ni-Mo systems of type A and B according to the classification of MIS are widely used for surfacing abrasive-wearing products. At present, the powder wires of this system produced by DRATEC (Germany) DT-SG 600 F and powdered wires by ESAB OK Tubrodur 15.52, OK Tubrodur 58 O/G M are widely used in our country. By the results of researches it is necessary to define a field of application of wires of different types in details of mining machines.

2. Methods of research

The chemical composition of the weld samples under investigation was determined according to GOST 10543-98 (Russian National Standard) by the X-ray fluorescence method on XRF-1800 spectrometer and by the atomic-emission method using DFS-71 spectrometer. The hardness of the samples studied was measured with MET-DU hardness tester. The wear resistance tests were carried



out on the machine 2070 SMT-1. The tests were carried out in the following regimes: load 30 mA, frequency 20 rpm. The metallographic analysis was carried out using OLYMPUS GX-51 optical microscope in a light field in the magnification range of 100-1000 after etching in alcoholic nitric acid solution. The grain size was determined in accordance with GOST 5639-82 at magnification $\times 100$. The size of the martensite needles was determined in accordance with GOST 8233-56 at magnification $\times 1000$. Investigation of longitudinal samples of the surfaced layer for the presence of nonmetallic inclusions was made in accordance with GOST 1778-70 at magnification $\times 100$.

3. Results and discussion

This work continues the research devoted to the development of new compositions of powder wires used for surfacing products working under abrasive wear in the mining industry [16 - 18], in particular, the study of the effect of the use of vanadium and cobalt in the production of wire samples of Fe-C-Si-Mn-Cr-Mo-Ni system on the degree of wear and hardness of the deposited layer.

The wire was manufactured on a laboratory machine. Diameter of wire 5 mm, the cover is made from a strip St3. As a filler the appropriate powdered materials were used: PZhV1 iron powder according to GOST 9849-86, ferrosilicon powder FS 75 according to GOST 1415-93, high-carbon ferrochromium powder FH900A according to GOST 4757-91, powder carbon ferromanganese 78 FMn (A) according to GOST 4755-91, PNK-1L5 nickel powder 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 PC-1U according to GOST 9721-79. As carbon-containing component dust from gas cleaning of aluminum production was used with the following component composition, wt%: $\text{Al}_2\text{O}_3 = 21-46.23$; $\text{F} = 18-27$; $\text{Na}_2\text{O} = 8-15$; $\text{K}_2\text{O} = 0.4-6$; $\text{CaO} = 0.7-2.3$; $\text{Si}_2\text{O} = 0.5-2.48$; $\text{Fe}_2\text{O}_3 = 2.1-3.27$; $\text{C}_{\text{tot}} = 12.5-30.2$; $\text{MnO} = 0.07-0.9$; $\text{MgO} = 0.06-0.9$; $\text{S} = 0.09-0.19$; $\text{P} = 0.1-0.18$.

Surfacing by the produced wire was made under the flux of AN-26C, on plates of steel grade St3 in 6 layers (to exclude the intermixing of the welded metal with the substrate), using ASAW-1250 welding tractor in the deposition regime: $I = 450 \text{ A}$, $U = 30 \text{ B}$, $V = 10 \text{ cm/min}$. The plates were then cut into the appropriate test samples. The chemical composition of the deposited layers by powdered wires is given in Table 1.

Metallographic studies showed that the microstructure of the deposited layer by the flux-cored wire of Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system is uniform, thin branches of dendrites are observed. The microstructure consists of martensite formed within the boundaries of the former austenite grain, austenite residual, present in a small amount in the form of separate islets, and thin δ -ferrite layers located along the boundaries of the former austenite grains.

It was established that in the microstructure of samples with a carbon content of 0.22-0.55% (samples No. 1-6), fine-needle martensite with needle size up to 6 μm is observed (point No. 4). The value of the former austenite grains on the grain scale is within the limits of No. 6-7 (figure 1, 2, table 2).

Table 1. Chemical composition, hydrogen content, wear and hardness of the deposited layers.

Sample number	Element mass fraction, %														[H], cm ³ /100g	Samples hardness, HRC	Samples wear g/r
	C	Si	Mn	Cr	Ni	Mo	B	V	Co	Al	Cu	Ti	S	P			
1	0.22	0.35	0.65	2.78	0.09	0.25	0	0.02	0.04	0.01	0.06	0.01	0.036	0.020	2.0	36	0.000040
2	0.43	0.37	0.84	7.04	0.42	0.49	0.01	0.03	0.06	0.02	0.08	0.01	0.038	0.020	2.0	56	0.000020
3	0.5	0.68	0.75	5.57	0.44	0.55	0.01	0.04	0.1	0.03	0.07	0.003	0.037	0.025	2.0	50	0.000015
4	0.55	0.81	0.7	5.59	0.6	0.58	0.01	0.03	0.11	0.07	0.07	0.005	0.044	0.023	2.4	53	0.000005
5	0.46	0.68	0.75	5.04	0.72	0.5	0.01	0.03	0.08	0.05	0.1	0.001	0.042	0.019	2.1	51	0.000071
6	0.44	0.74	0.73	5.59	0.86	0.53	0.01	0.03	0.09	0.06	0.07	0.02	0.038	0.020	2.3	52	0.000017
7	0.19	0.77	0.61	4.17	0.34	0.38	0.01	0.02	0.05	0.01	0.07	0.02	0.054	0.024	2.4	44.5	0.000071
8	0.19	0.63	0.65	4.06	0.3	0.38	0.01	0.03	0.06	0.01	0.08	0.03	0.056	0.019	1.7	43	0.000039
9	0.2	0.59	0.61	4.12	0.3	0.38	0.01	0.02	0.12	0.02	0.06	0.04	0.049	0.019	1.9	46	0.000044
10	0.2	0.64	0.6	4.03	0.3	0.39	0.01	0.03	0.2	0.01	0.08	0.03	0.058	0.021	2.0	30	0.000073

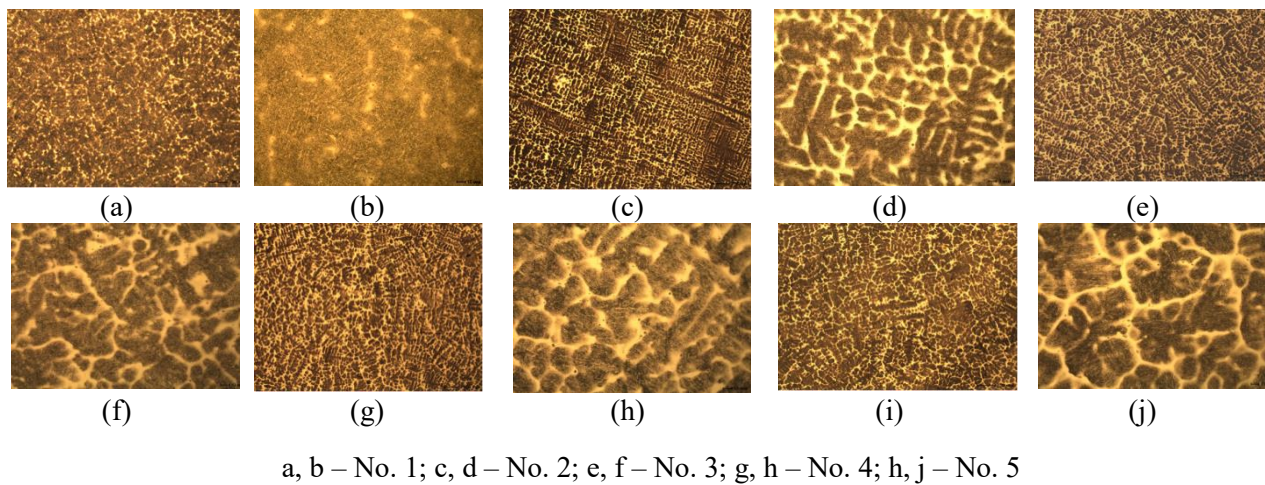


Figure 1. Microstructure of the examined samples, (a, c, e, g, i $\times 100$), (b, d, f, h, j $\times 500$).

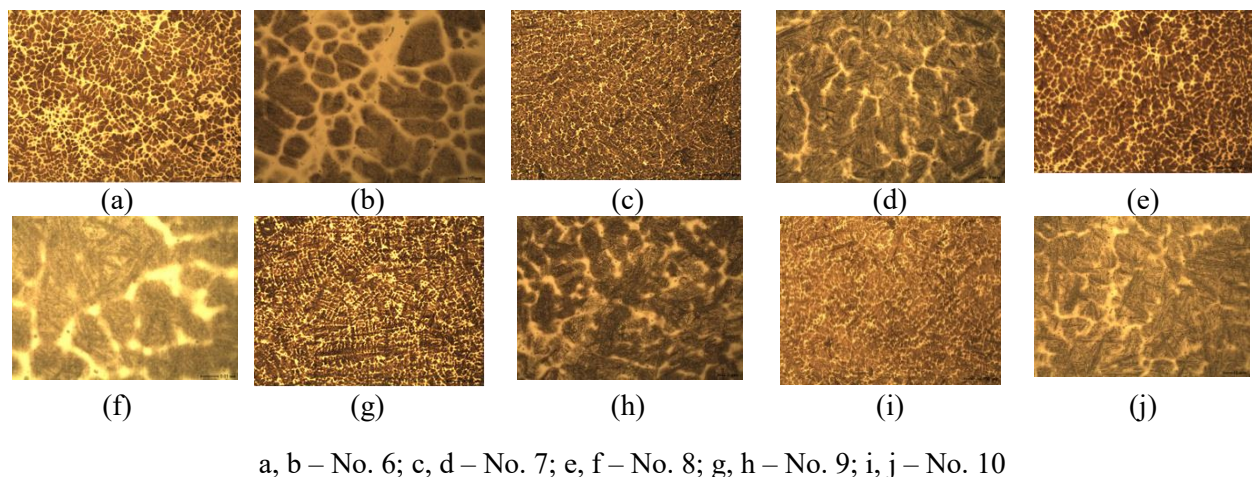


Figure 2. Microstructure of the examined samples, (a, c, e, g, i $\times 100$), (b, d, f, h, j $\times 500$).

As a result of a decrease in the carbon content in the deposited layer to 0.19-0.2% with a simultaneous change in the content of chromium, nickel, molybdenum and other elements present in its composition, the martensite needles are enlarged and the size of the former austenite grains is increased (figure 2).

It is shown that in the microstructure of samples No. 7-10 there is a medium needle (point No. 5) and a large needle (point No. 7) martensite with a needle size of 8-13 μm . The value of the primary austenite grain corresponds to No. 6 (figure 2, table 2).

As a result of the assessment of contamination of the welded layer with nonmetallic inclusions, the presence of oxide nonmetallic inclusions, in particular non-deforming silicates and point oxides (Table 2), was identified.

The influence of chemical composition of powdered wires belonging to Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system on the degree of wear and the hardness of the deposited layer was estimated by means of multivariate correlation analysis, which makes it possible to study the regularities of the change in the resulting index depending on the behavior of various factors by the methods described in [19, 20, 21].

Table 2. Characteristics of nonmetallic inclusions and structure of the examined samples.

Sample number	Contamination with non-metallic inclusions, points		Value of austenite grain, point	Size of martensite needles, μm
	Silicates non-deforming (brittle)	Spot oxides		
1	2b, 1b, 2a	1a	6, 7	3-6
2	2b, 1b, 3a	1a	7	2-6
3	1b, 2b, 3a	1 a	7	2-6
4	2b, 1b, 2a, 3a	1 a	6, 7	4-6
5	1b, 2b, 3a	1 a	6, 7	3-6
6	1b, 2b, 3a	1 a	7, 6	2-6
7	1b, 2a	1 a	6	8-13
8	1b, 2b, 2a, 3a	1 a, 2a	6	8-10
9	1b, 2b, 2a, 3a	1 a, 2a	6	8-12
10	1b, 2b, 3a	1 a, 2a	6	8-11

For the analysis the factors that influence the investigated indicator were identified, 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. Next, a model of the factor system was constructed. Since the above systems have independent factors 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 straightforward character, which is confirmed by the coefficient of determinacy, which for models of reduced factor systems is equal to 1.

Calculation of the main connection indicators of 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 connection equation 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 to actual values was checked by the average error of approximation:

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

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

Dependences of the deposited layer hardness and its wear resistance on the mass fraction of the elements that form composition of the powder wires of Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system obtained as a result of the analysis:

- hardness of the deposited layer (without taking into account the hydrogen content):
 $y = 535.343 + 168.120 \cdot C - 276.437 \cdot Si - 890.442 \cdot Mn + 6.037 \cdot Cr + 108.957 \cdot Ni + 445.851 \cdot Mo - 433.688 \cdot Co - 1014.594 \cdot Al + 477.567 \cdot Cu$ (approximation error 0.01%);
- hardness of the deposited layer (taking into account the hydrogen content):
 $y = 214.819 - 163.253 \cdot C - 307.499 \cdot Si - 353.293 \cdot Mn - 21.239 \cdot Cr + 33.871 \cdot Ni + 858.517 \cdot Mo - 280.917 \cdot Co + 321.784 \cdot Cu + 13.830 \cdot H$ (approximation error 0.01%);
- wear resistance of samples (without taking into account the hydrogen content):
 $y = 0.002005 + 0.001110 \cdot C - 0.000804 \cdot Si - 0.003522 \cdot Mn + 0.000040 \cdot Cr + 0.000500 \cdot Ni + 0.000460 \cdot Mo - 0.001061 \cdot Co - 0.005525 \cdot Al + 0.003132 \cdot Cu$ (approximation error 0.32%);
- wear resistance of samples (taking into account the hydrogen content):
 $y = 0.000260 - 0.000695 \cdot C - 0.000973 \cdot Si - 0.000597 \cdot Mn - 0.000108 \cdot Cr + 0.000091 \cdot Ni + 0.002707 \cdot Mo - 0.000229 \cdot Co + 0.002283 \cdot Cu + 0.000075 \cdot H$ (approximation error 10.74%).

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.

As a result of the multifactor correlation analysis, the dependencies of deposited layer hardness and its wear resistance on the mass fraction of the elements in the composition of the powder wires of Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system were determined. 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.

4. Conclusions

1. It was established that the decrease in the carbon content in the deposited layer up to 0.19-0.2% with a simultaneous change in the content of chromium, nickel, molybdenum and other elements present in it contributes to the enlargement of martensite needles and an increase in the size of the former austenite grain.

2. Based on the results of multifactor correlation analysis, the dependencies of the deposited layer hardness and its wear resistance on the mass fraction of the elements included in the powder wires of the Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system were determined. The obtained dependences can be used to predict the hardness of the deposited layer and its wear resistance under different modes of operation of parts in mining and coal-mining equipment.

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