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## Quality of Metal Deposited Flux Cored Wire With the System Fe-C-Si-Mn-Cr-Mo-Ni-V-Co

Aleksander I Gusev<sup>1</sup>, Nikolay A Kozyrev<sup>1, a</sup>, Ivan V Osetkovskiy<sup>1</sup>, Roman E Kryukov<sup>1</sup>, Olga A Kozyreva<sup>2</sup>

<sup>1</sup> Siberian IndustrialStateUniversity

654007, Russia, Kemerovo region, Novokuznetsk, Kirova street, 42

<sup>2</sup> KemerovoStateUniversity, 6, Krasnay street, Kemerovo, 650000

E-mail: <sup>a</sup> Kozyrev na@mtsp.sibsiu.ru

Abstract: Studied the effect of the introduction of vanadium and cobalt into the charge powder fused wire system Fe-C-Si-Mn-Cr-Ni-Mo-V, used in cladding assemblies and equipment parts and mechanisms operating under abrasive and abrasive shock loads. the cored wires samples were manufactured in the laboratory conditions and using appropriate powder materials and as a carbonfluoride contained material were used the dust from gas purification of aluminum production, with the following components composition, %: Al<sub>2</sub>O<sub>3</sub> = 21-46.23; F = 18-27; Na<sub>2</sub>O = 8-15; K<sub>2</sub>O = 0.4-6; CaO = 0.7-2.3; Si<sub>2</sub>O = 0.5-2.48; Fe<sub>2</sub>O<sub>3</sub> =  $\frac{1}{2}$ 2.1-3.27; C = 12.5-30.2; MnO = 0.07-0.9; MgO = 0.06-0.9; S = 0.09-0.19; P = 0.1-0.18. Surfacing was produced on the St3 metal plates in 6 layers under the AN-26C flux by welding truck ASAW-1250. Cutting and preparation of samples for research had been implemented. The chemical composition and the hydrogen content of the weld metal were determined by modern methods. The hardness and abrasion rate of weld metal had been measured. Conducted metallographic studies of weld metal: estimated microstructure, grain size, contamination of oxide non-metallic inclusions.

Metallographic studies showed that the microstructure of the surfaced layer by cored wire system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co is uniform, thin dendrite branches are observed. The microstructure consists of martensite, which is formed inside the borders of the former austenite grain retained austenite present in small amounts in the form of separate islands, and thin layers of  $\delta$ -ferrite, which is located on the borders of the former austenite grains.

Carried out an assessment the effect of the chemical composition of the deposited metal on the hardness and wear and hydrogen content. In consequence of multivariate correlation analysis, it was determined dependence to the hardness of the deposited layer and the wear resistance of the mass fraction of the elements included in the flux-cored wires of the system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co. The calculated value of the average approximation error suggests that the dependence is adequate and can be used to determine the resulting indicators. These dependencies can be used to predict the hardness of the deposited layer and its wear resistance while changing the chemical composition of the weld metal.

#### Introduction

Mining equipment machines and mechanisms which work in abrasive and abrasive-shock conditions, breaks down early. Wear of working surface cause necessity for its recovering. That is why developing materials which could increase wear resistance of such details and technologies of their recovering is important purpose. Most advanced is the use of cored wires for depositing on the



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wearing out surface of details. For this reason, in our and foreign countries is conducted the development and manufacture of special surfacing cored wires [1-14]. Due to optimal selection of doping method, deposited coatings exhibit high level of hardness, abrasive and abrasive-shock wear resistance. Widespread flux cored wires of system Fe-C-Si-Mn-Cr-Ni-Mo classification type A and B by International Institute of Welding are for depositing coatings on wearing out items surface [15]. Currently flux cored wires of this system manufactured by the firm DRATEC (Germany) brand DT-SG 600 F and other cored wires firm ESAB brands OK Tubrodur 15.52, OK Tubrodur 58 O/G M are widely used in our country.

#### Materials and methods of research

This work continues the research started to develop new formulations of flux-cored wires for overlaying products working in conditions of abrasive wear in the mining industry [16-18], particularly researching the influence of vanadium and cobalt on the level of wear and hardness of surfaced coating once manufacturing test wire samples of system Fe-C-Si-Mn-Cr-Mo-Ni.

Manufacturing of powder wire was conducted on laboratory machine. Diameter of powder wire is 5mm, wire shell is made from metal ribbon of St3 grade. As a filler were used respective powder materials: iron powder brand GJW1 by GOST 9849-86, ferrosilicon powder brand  $\Phi$ C 75 by GOST 1415-93, powder of high carbon ferrochrome brand FH900A by GOST 4757-91, powder of carbon ferromanganese FMn 78(A) by GOST 4755-91, nickel powder PNK-1L5 by GOST 9722-97, ferromolybdenum powder brand FMo60 by GOST 4759-91, ferrovanadium powder brand FW50U 0,6 by GOST 27130-94, cobalt powder brand PK-1U by GOST 9721-79, plus as carbon-contained component dust was used from gas scrubbing of aluminum production, with the following component composition, wt.%: Al<sub>2</sub>O<sub>3</sub> = 21-46.23; F = 18-27; Na<sub>2</sub>O = 8-15; K<sub>2</sub>O = 0.4-6; CaO = 0.7-2.3; Si<sub>2</sub>O = 0.5-2.48; Fe<sub>2</sub>O<sub>3</sub> = 2.1-3.27; C = 12.5-30.2; MnO = 0.07-0.9; MgO = 0.06-0.9; S = 0.09-0.19; P = 0.1-0.18.

Surfacing was conducted by manufactured wire under the AN-26S flux, on the metal plates of the brand St3 in 6 layers (to avoid mixing the weld metal with substrate) with the use of welding tractor ASAW-1250, with the following surfacing conditions: I=450 A, U=30 B, V=10 cm/min. Further plates were cut into appropriate test specimens. Chemical composition of the test specimens were defined by GOST 10-543-98 X-ray fluorescence method on spectrometer XRF-1800 and atomic emission method on spectrometer DFS-71. Chemical composition of the surfaced metal is shown in table 1. Hardness of the researched samples was measured with the use of hardness meter MET-DU. Wear resistance tests of samples was conducted on machine SMT-1 with the following conditions: capacity 30 mA, rate 20 rmp. Metallographic analysis was conducted on optical microscope OLYMPUS GX-51 in the light field in the limits of range ×100-1000 magnification after etching samples by 4% nital to determine the degree of influence changes in chemical composition on parameters of the microstructure. Martensite needles size was determined by GOST 8233-56 with × 1000 magnification. Studying of longitudinal deposited metal samples on nonmetallic inclusions existence was conducted in according with GOST 1778-70 with ×100 magnification.

Metallographic researches shown, that microstructure of surfaced layer by flux coder wire system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co is uniform, there are thin dendritic branches. The microstructure consists of martensite, which is formed inside the borders of the former austenite grain, retained austenite, which is presented in small amounts in the form of separate islands, and thin layers of  $\delta$ -ferrite, which is located on the borders of the former grain austenite.

It is found that the microstructure of the samples with a carbon content of 0.22 - 0.55% (samples  $N_{2} 1-6$ ) observed fine-needled martensite with the needles size up to 6 microns (rating N<sub>2</sub>4). The size of the former austenite grain conforms to scales ranges N<sub>2</sub>6 - 7 (figure 1a, b, table 2).

By reducing the carbon content in the deposited layer to 0.19-0.2% while varying chromium, nickel, molybdenum and other present components in its composition, there is coarsening of the martensite needles and increasing the size of the former austenite grains (figure 1b, table 2).



i j Fig. 1a. Microstructure of the researched samples, (a, c, e, g,  $i \times 100$ ), (b, d, f, h,  $j \times 500$ ): a, b - N $^{\circ}1$ ; c, d-N $^{\circ}2$ ; e, f -N $^{\circ}3$ ; g, h-N $^{\circ}4$ ; i, j- N $^{\circ}5$ 



i j Fig. 2b. Microstructure of the researched samples, (a, c, e, g,  $i \times 100$ ), (b, d, f, h,  $j \times 500$ ): a, b-N $_{2}6$ ; c, d-N $_{2}7$ ; e, f -N $_{2}8$ ; g, h -N $_{2}9$ ; i, j-N $_{1}10$ 

Sample number	Components weight content %													[H], cm <sup>3</sup> /	Samples	Samples wear, grams	
	С	Si	Mn	Cr	Ni	Мо	В	v	Co	Al	Cu	Ti	S	Р	100 g	HRC	per revolution.
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

Table 1 - Surfaced layers' chemical composition, hydrogen contain, wear and hardness

Table 2 - Characteristics of non-metallic inclusions and the structure of researched samples

Samplenumber	The contamination by nonmetallic	Size of austenite	Size of	
	raiting		gaine, raiting	martensite
	non-deformable silicates	Oxides		needles, mcn
	(fragile)	spot		
1	2b, 1b, 2a	1a	6, 7	3-6
2	2b, 1b, 3a	1a	7	2-6
3	1b, 2b, 3a	1a	7	2-6
4	2b, 1b, 2a, 3a	1a	6, 7	4-6
5	1b, 2b, 3a	1a	6, 7	3-6
6	1b, 2b, 3a	1a	7,6	2-6
7	1b, 2a	1a	6	8-13
8	1b, 2b, 2a, 3a	1a, 2a	6	8-10
9	1b, 2b, 2a, 3a	1a, 2a	6	8-12
10	1b, 2b, 3a	1a, 2a	6	8-11

Assessing the influence of the flux-cored wires with chemical composition system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co on wear and hardness of the deposited layer was carried out by means of multivariate correlation analysis, which allows to study the patterns of change in the resulting index, which depends on the behavior of various factors, the procedures set forth in the works [19, 20, 21].

To conduct the analysis were determined factors, that influence on resulting index, and then were selected most essential of them (table 1). After this initial check was made on the accuracy of the information, it's uniformity and conformity to the law of normal distribution. Further the model of factorial system was built. Deterministic factor analysis is used, because of presence of independent factorial signatures in the reduced system.

The connection type was determined using paired and partial correlation coefficients. It was found that the relationship has a rectilinear character, as evidenced by the same factor determinism, which is for the model of reduced factorial systems equal 1.

Calculation the key link indicators of correlation analysis was carried out in stages. Firstly, the first factor was considered, which influence is the most significant, then the second, third etc. At each stage the constraint equation and the parameters were calculated, by means of which was estimated its reliability.

Per the results of calculations obtained dependencies, the adequacy of which was checked by actual values in index of the average approximation error:

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

m - the number of observations;  $Y_i$  – calculated value of resulted index;  $Y_i$  – real value of resulted index.

Hardness and wear resistance dependencies of deposited metal from its mass fraction of the elements included in the cored wire system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co obtained in consequence of the analysis:

- Hardness of the deposited metal (with no regard for contained hydrogen):  $y=535.343 + 168.120 \cdot C$ - 276.437·Si - 890.442·Mn + 6.037·Cr + 108.957·Ni + 445.851·Mo - 433.688·Co - 1014.594·Al + 477.567·Cu (approximation error 0.01%);

- Hardness of the deposited metal (with the regard for contained hydrogen):  $y=214.819 - 163.253 \cdot C - 307.499 \cdot Si - 353.293 \cdot Mn - 21.239 \cdot Cr + 33.871 \cdot Ni + 858.517 \cdot Mo - 280.917 \cdot Co + 321.784 \cdot Cu + 13.830 \cdot H$  (approximation error 0.01%);

- Wear resistance of the samples (with no regard for contained hydrogen):  $y=0.002005 + 0.001110 \cdot C - 0.000804 \cdot Si - 0.003522 \cdot Mn + 0.000040 \cdot Cr + 0.000500 \cdot Ni + 0.000460 \cdot Mo - 0.001061 \cdot Co - 0.005525 \cdot A1 + 0.003132 \cdot Cu (approximation error 0.32%);$ 

- Wear resistance of the samples (with the regard for contained hydrogen):  $y=0.000260 - 0.000695 \cdot C - 0.000973 \cdot Si - 0.000597 \cdot Mn - 0.000108 \cdot Cr + 0.000091 \cdot Ni + 0.002707 \cdot Mo - 0.000229 \cdot Co + 0.002283 \cdot Cu + 0.000075 \cdot H (approximation error 10.74%).$ 

Calculated values of average approximation errorargue that obtained dependencies are adequate and they can be used to define the resulted indexes.

In consequence of multivariate correlation analysis, it was determined dependence to the hardness of the deposited layer and the wear resistance of the mass fraction of the elements included in the flux-cored wires of the system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co.

#### **Conclusions.**

1. It is found that, by reducing carbon contained in the surfaced metal down to 0.19-0.2% while changing contain of chromium, nickel, molybdenum and other present components in its composition, promotes increasing in the size of martensite needles and former grain austenite.

2. In consequence of multivariate correlation analysis, it was determined dependence to the hardness of the deposited layer and the wear resistance of the mass fraction of the elements included in the flux-cored wires of the system Fe-C-Si-Mn-Cr-Mo-Ni-V-Co. These dependencies can be used to predict the hardness of the deposited layer and its wear resistance while changing the chemical composition of the weld metal.

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