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To cite this article: A I Gusev et al 2018 IOP Conf. Ser.: Earth Environ. Sci. 206 012034

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Development of a flux-cored wire for surfacing mining equipment operating in the conditions of shock-abrasive wear

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Abstract. The effect of introducing various elements into the charge of a powder surfacing wire was studied. The dependences of the deposited layer hardness and its wear resistance on the mass fraction of the elements that make up the powder wires were determined by the method of multifactor correlation analysis. A new composition of the flux-cored wire used for surfacing mining equipment operating in the conditions of abrasive wear was developed.

1. Introduction

One of the most important reserves for increasing the production volume and extension of the equipment lifetime is the increase in the efficiency of the actuation component of shearer-loaders and tunneling combines operating in the conditions of shock abrasive wear. The development of new materials that significantly increase the wear resistance of such parts and the use of technology for their recovery is a very important and urgent task [1-10]. Welding wires of Fe-C-Si-Mn-Cr-Ni-Mo systems of type A and B, according to the classification of MIS [11], have become widespread for surfacing the wearing parts.

2. Methods of research

The laboratory studies were carried out according to the scheme described in [12-13]. Multilayer surfacing of the samples was carried out with preheating of the plates to 3500C and subsequent (after surfacing) slowed cooling. Surfacing on the plates was carried out by the welding tractor ASAW-1250 using the produced flux-cored wire. The following components were introduced into wire samples: nickel, cobalt, tungsten; amorphous carbon was replaced by carbon-fluorine-containing dust, with the following chemical composition, wt. %: $Al_2O_3 = 21-46$; F = 18-27; $Na_2O = 8-15$; $K_2O = 0.4-6\%$; CaO = 0.7 - 2.3; $SiO_2 = 0.5 - 2.5$; $Fe_2O_3 = 2.1 - 3.3$; $C_{tot} = 12.5 - 30.2$; MnO = 0.07 - 0.9; MgO = 0.06 - 0.9; S = 0.09-0.19; P = 0.10-0.18. The wire was manufactured on a laboratory machine.

The diameter of the manufactured wire was 5 mm, the casing was made of St3 tape. Powder-like materials were used as a filler: powder of iron of grade PZhV1 according to state standards GOST 9849-86, ferrosilicon powder of grade FS 75 according to GOST1415-93, powder of high-carbon ferrochromium grade FK900A according to GOST 4757-91, powder of carbon ferromanganese FMn 78 (A) according to GOST 4755-91, nickel powder PNK-1L5 according to GOST 9722-97, ferromolybdenum powder of FMo60 grade according to GOST 4759-91, ferrovanadium powder of grade FV50U 0.6 according to GOST 27130-94, cobalt powder PC-1U according to GOST 9721-79, tungsten powder PVN TU 48-19-72-92.

The chemical composition of the weld metal was determined by the X-ray fluorescence method on XRF-1800 spectrometer and by the atomic-emission method using DFS-71 spectrometer (table 1). The

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hardness of the test samples was measured by the Rockwell method in accordance with the requirements of GOST 9013-59.

Metallographic examination of thin sections was carried out using an optical microscope OLYMPUSGX-51 in a bright field in the magnification range ×100-1000 after etching the samples surface in the 4% solution of nitric acid. The grain size was determined in accordance with GOST 5639-82 with an magnification × 100. The martensite dispersion was evaluated by comparing the structure with the standards of the corresponding scales and the sizes of martensite needles with the data of table No. 6 of GOST 8233-56. Determination of the martensite needles length was carried out using a package of applied software for metallographic studies SiamsPhotolab 700. The investigation of longitudinal samples of the welded layer for the presence of nonmetallic inclusions was carried out in accordance with GOST 1778-70. The polished surface was studied with an increase ×100 by LaboMet-1I metallographic microscope. The abrasion rate of the welded layer of the prototypes was determined by testing for wear on the machine 2070 SMT-1 according to the disk-welding die scheme.

3. Results and discussion

The chemical composition of the weld metal is given in table 1. Metallographic studies (table 2) shows that the microstructure of the deposited layer by the flux-cored wire of the Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system consists of martensite formed within the boundaries of the former austenitic grains, residual austenite, present in a small amount in the form of separate islands, and thin δ -ferrite layers located along the boundaries of the former austenite grains, in the absence of chromium it has a ferrite-pearlitic structure.

It is believed that the most favorable bases for wear-resistant alloys used for restoration of equipment parts is martensitic and austenitic. In this case, depending on the general structure of the alloy and the presence of excess phases, in different cases one or another base may be preferable. The combination of these two bases (martensite with a certain amount of austenite) can provide the most favorable combination of the welded alloy properties.

The analysis of the obtained results shows that the degree of influence of various chemical elements on the hardness of the welded layer and the samples wear rate is different. Within the studied ranges carbon, chromium, molybdenum, nickel, manganese and, to an insignificant extent, vanadium simultaneously increase the hardness of the deposited layer and decrease the wear rate of the samples. When studying the effect of the use of tungsten and cobalt on the properties of the deposited layer, it has been established that an increase in the concentration of tungsten slightly increases the hardness of the weld metal, but at the same time the wear resistance decreases. This, apparently, is associated with a high-strength solid martensitic matrix, in which more solid carbides of tungsten are "built-in". The low viscosity of the matrix does not allow the tungsten carbides to be retained on the surface, as a result of which the wear is not carried out according to the scheme of uniform surface abrasion, but according to the scheme of high-strength carbide particles pitting from the matrix, as a result of which cracks are formed in the matrix, thus, contributing to additional wear of the matrix.

С	Si	Mn	Cr	Mo	Ni	Al	Co	Cu	W	Ti	V	S	Р
0.4	0.7	0.8	5.2	0.5	0.4	0.02	0.1	0.0	0.00	0.00	0.05	0.03	0.02
0.4	0.8	0.7	4.9	0.5	0.5	0.02	0.11	0.0	0.00	0.00	0.04	0.04	0.02
0.2	0.7	0.7	5.5	0.4	0.6	0.02	0.08	0.1	0.00	0.00	0.04	0.04	0.01
0.3	0.6	0.8	4.9	0.4	0.8	0.02	0.09	0.0	0.00	0.02	0.04	0.03	0.02
0.1	0.7	0.6	4.1	0.3	0.3	0.10	0.05	0.0	0.00	0.01	0.02	0.05	0.02
0.1	0.6	0.6	4.0	0.3	0.3	0.06	0.05	0.0	0.00	0.02	0.03	0.05	0.01
0.2	0.5	0.6	4.1	0.3	0.3	0.03	0.12	0.0	0.00	0.00	0.02	0.04	0.01
0.2	0.6	0.6	4.0	0.3	0.3	0.05	0.19	0.0	0.00	0.02	0.03	0.05	0.02
0.2	0.5	0.5	0.0	0.3	0.3	0.01	0.05	0.1	7.74	0.00	0.00	0.07	0.01
0.2	0.5	0.4	0.0	0.3	0.2	0.02	0.07	0.0	7.42	0.00	0.01	0.04	0.01
0.2	0.5	0.5	0.0	0.3	0.2	0.05	0.07	0.0	7.55	0.00	0.01	0.03	0.01
	C 0.4 0.2 0.3 0.1 0.1 0.2 0.2 0.2 0.2 0.2	C Si 0.4 0.7 0.4 0.8 0.2 0.7 0.3 0.6 0.1 0.7 0.1 0.6 0.2 0.5 0.2 0.5 0.2 0.5 0.2 0.5 0.2 0.5 0.2 0.5 0.2 0.5 0.2 0.5 0.2 0.5	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$										

Table 1. Chemical composition of deposited layers.

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61		o -	o -	0.0	~ ^	• •	0 0 -	0.07	0.0		0.00	0.00	0.00	0.01
GI6	0.2	0.5	0.5	0.0	0.3	0.2	0.05	0.06	0.0	7.65	0.00	0.02	0.03	0.01
G131	0.2	0.7	1.4	7.1	0.3	0.3	0.08	0.00	0.0	0.00	0.01	0.02	0.03	0.00
G141	0.2	0.7	1.3	5.9	0.3	0.2	0.09	0.	0.0	0.00	0.03	0.03	0.02	0.01
G151	0.2	0.7	1.2	6.3	0.3	0.3	0.08	0.00	0.0	0.00	0.00	0.02	0.03	0.01
G161	0.2	0.7	1.1	6.0	0.3	0.3	0.07	0.	0.0	0.00	0.02	0.04	0.03	0.01
G17	0.1	0.5	0.9	3.9	0.2	0.2	0.02	0.00	0.0	0.03	0.00	0.00	0.03	0.01
G18	0.1	0.6	1.2	6	0.3	0.3	0.01	0.00	0.1	0.02	0.00	0.00	0.03	0.01
G19	0.1	0.5	1.1	5.9	0.3	0.3	0.00	0.00	0.0	1.64	0.00	0.00	0.03	0.01
G20	0.1	0.4	0.9	4.1	0.2	0.2	0.00	0.00	0.0	0.02	0.00	0.03	0.03	0.01
G21	0.1	0.5	1.1	6.2	0.3	0.4	0.00	0.00	0.0	0.02	0.00	0.04	0.03	0.01
G22	0.2	0.6	0.9	4.1	0.4	0.2	0.03	0.01	0.0	0.04	0.00	0.00	0.02	0.01
G23	0.2	0.6	0.9	3.5	0.3	0.2	0.02	0.02	0.0	4.66	0.00	0.00	0.03	0.01
G24	0.2	0.7	1.0	4.1	0.3	0.2	0.03	0.19	0.0	0.08	0.00	0.00	0.03	0.01

Table 2. Characteristics of the deposited metal.

Sample No.	Structure	Austenite grain size	HRC	Abrasion rate, G/rev
G5	Martensit	7	49	0.0000140
G6	Martensit	6 and 7	52	0.0000056
G7	Martensit	6	50	0.0000710
G8	Martensit	6 and 7	52	0.0000140
G9	Martensit	6 and 7	44.5	0.0000710
G10	Martensit	6 and 7	42.5	0.0000390
G11	Martensit	6 and 7	42.5	0.0000440
G12	Martensit	6 and 7	37	0.0000730
G13	Ferrito-perlite	5 and 6	22.5	0.0002060
G14	Ferrito-perlite	6	25.5	0.0000480
G15	Ferrito-perlite	5	22	0.0000360
G16	Ferrito-perlite	6	26	0.0000390
G131	Martensit	7	55	0.0000280
G141	Martensit	7	41	0.0000550

Continuation of Table 2.

Sample No.	Structure	Austenite grain size	HRC	Abrasion rate, G/rev
G151	Martensit	7	45	0.0000074
G161	Martensit	7	45	0.0000340
G17	Martensit	6-7;	40	0.0000280
G18	Martensit	6	45	0.0000540
G19	Martensit	6	49	0.0000430
G20	Martensit	6-7;	38	0.0001420
G21	Martensit	6	48	0.0000550
G22	Martensit	6	43	0.0000330
G23	Martensit	6-7;	49	0.0000650
G24	Martensit	6-7;	42	0.0000300

The introduction of cobalt into the composition of the charge does not significantly affect the hardness and abrasive wear of the deposited layer, which is associated with the production of a more viscous but less rigid matrix. In the absence of solid carbide particles embedded in the matrix, the effect of cobalt introduction is negative. It should be also noted that the influence of tungsten on the deposited layer hardness and the samples wear rate is primarily related to the structure of the metal matrix, and the replacement of the mattensitic structure in the deposited layer with ferrite-pearlitic one also has little positive effect on wear resistance.

 IOP Conf. Series: Earth and Environmental Science 206 (2018) 012034
 doi:10.1088/1755-1315/206/1/012034



IOP Conf. Series: Earth and Environmental Science 206 (2018) 012034 doi:10.1088/1755-1315/206/1/012034



Figure 1. Microstructure of the deposited layers $\times 100$.

The evaluation of the influence of powder wires chemical composition on the wear rate and hardness of the welded layer was carried out by mathematical and statistical methods that allow the patterns of variation of the resulting index depending on various factors to be studied using the methods described in [14, 15].

The dependences of the deposited layer hardness and its wear resistance on the mass fraction of elements were obtained.

Hardness of the welded layer:

HRC=35.884+22.840·C+11.079·Si-15.903·Mn+4.785·Cr+10.118·Mo+1.399·Ni-38.964·Al-

24.126·Co-65.841·Cu-0.057·W+17.887·Ti-76.116·V-76.351·S-239.206·P (approximation error is 4.2%);

Rate of samples wear (W):

 $\label{eq:w-0.00025-0.00034} \\ \cdot C + 0.000171 \\ \cdot Si + 0.000144 \\ \cdot Mn \\ - 0.00008 \\ \cdot Cr \\ - 0.00014 \\ \cdot Mo \\ + 0.00017 \\ \cdot Ti \\ + 0.000633 \\ \cdot V \\ + 0.002836 \\ \cdot S \\ + 0.005644 \\ \cdot P \mbox{ (approximation error is $8.14\%)}.$

Testing of the new flux-cored wire was carried out on the plates installed on drums 2 m in diameter of the shearer-loader JOY 4LS20 (figure 2). The results of the flux-cored wire research are protected by the patent of the Russian Federation [16].

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Figure 2. Protective plates on the drums of the shearer-loader JOY 4LS20.

4. Conclusions

1) Based on the research results and the multifactor correlation analysis, the dependences of the welded layer hardness and its wear resistance on the mass fraction of the elements that make up the powder wires of the Fe-C-Si-Mn-Cr-Mo-Ni-V-Co system are determined.

2) The obtained dependences are used to predict the hardness of the welded layer and its wear resistance when the chemical composition of the weld metal changes. The results of the flux-cored wire investigations were patented.

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