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# INFLUENCE OF THE COMPOSITION OF CHARGE COMPONENTS IN FLUX-CORED STRIPS OF C-Fe-Cr-Mo ALLOYING SYSTEM ON CHEMICAL AND STRUCTURAL HETEROGENEITY OF THE DEPOSITED METAL

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## ABSTRACT

It is generally known that wear resistance of the deposited layer in the above-mentioned alloys depends on the reinforcing phase characteristics, its concentration and qualities of the matrix alloy. The methods of X-ray structural, metallographic analyses and X-ray microanalysis of metal of 500Kh30M type deposited by flux-cored strips revealed the dependence of the concentration, form, orientation, phase components and integral hardness of the carbides on the method of adding chromium as the main carbide forming element, to the charge. It is found that the maximum concentration of the carbide phase of up to 80–90 % in the deposited layer is achieved at addition of  $\text{Cr}_3\text{C}_2$  chromium carbide to the flux-cored strip charge. Complex carbide systems —  $(\text{CrFe})_7\text{C}_3$  are mainly present in the deposited metal for all the samples. Molybdenum does not form any separate carbide compounds, but it is a component in carbides of  $(\text{Cr}_{2.5}\text{Fe}_{4.2}\text{Mo}_{0.2})\text{C}_3$  type. High concentration of the carbide component leads to carbide washout, in connection with a considerable reduction of the matrix alloy. Optimal concentration of the carbide phase in metal of 500X30M type deposited with flux-cored strip, is achieved by adding a carbide forming element — chromium to the electrode material charge in the proportion of 15–25 % chromium carbide and 75–85 % ferrochrome.

**KEY WORDS:** flux-cored strip, chromium carbide, ferrochrome, carbides, hardness, microstructure, matrix, concentration

## INTRODUCTION

Wear-resistant surfacing of parts by flux-cored wires or strips is one of the effective and widely used methods of their strengthening and increasing their service life [1–3]. A steadily growing demand to increase the equipment operability in different industries, makes it necessary to continuously improve the compositions and quality of electrode and filler materials for surfacing.

A wide range of parts of the mining and metallurgical complex are traditionally surfaced, using electrode (filler) materials, which allow producing deposited metal of the type of high-chromium cast iron, resistant to abrasive and gas-abrasive wear [4–6]. The effectiveness of such materials largely depends on the carbide phase concentration in the deposited metal, its orientation, structural components, as well as quality of the alloy matrix [7–9].

The above-mentioned characteristics of the deposited metal can differ essentially, depending on the chemical composition of the electrode and filler materials proper, as well as the composition of the charge of flux-cored wires and strips.

The objective of this work is investigation of the influence of carbide-forming components of the charge of PL-AN180 flux-cored strip on the structure

and phase components of the deposited metal and development of optimal composition of the flux-cored strip to produce a coating resistant to abrasive and gas-abrasive wear.

## INVESTIGATION PROCEDURES AND EQUIPMENT

Methods of X-ray structural, and metallographic analyses and X-ray microanalysis were used to study the deposited metal of 500Kh30M type. Hardness measurement was conducted in M-400 microhardness meter of LECO Company, and JAMP-9500F and DRON-UM1 instruments were used for X-ray spectral, electronic spectroscopy and X-ray diffraction studies. Microstructural studies were conducted using Neophot-32 microscope.

Sample surfacing was performed by electric arc method, using self-shielded flux-cored strip PL-AN180, which allows producing deposited metal of the following chemical composition, wt.%: 4.5 C; 30 Cr; 1 Mo. PL-AN180 flux-cored strip is used for producing wear-resistant bimetal plates of 5 to 30 mm thickness. Such bimetal plates are readily transformed into a wide range of parts for different metal structures, by laying-out, cutting and bending, thus extending their serviceability. These plates can be used to manufacture hoppers, conveyors, pipelines, dump truck bodies, lining of crushing and grinding

equipment, as well as other parts and structures which are exposed to intensive abrasive wear [10].

In C–Fe–Cr–Mo alloying system mainly chromium carbides are present as the reinforcing phase, and an iron-based alloy is the matrix. It was important to determine how the concentration of carbides and other characteristics of the deposited layer are affected by the form, in which the main carbide-forming element, namely chromium, is added to the charge. High-carbon ferrochrome of grade FKh900 and chromium carbide were used for chromium addition. The latter is close to stoichiometry of  $Cr_3C_2$  carbide in its chemical composition.

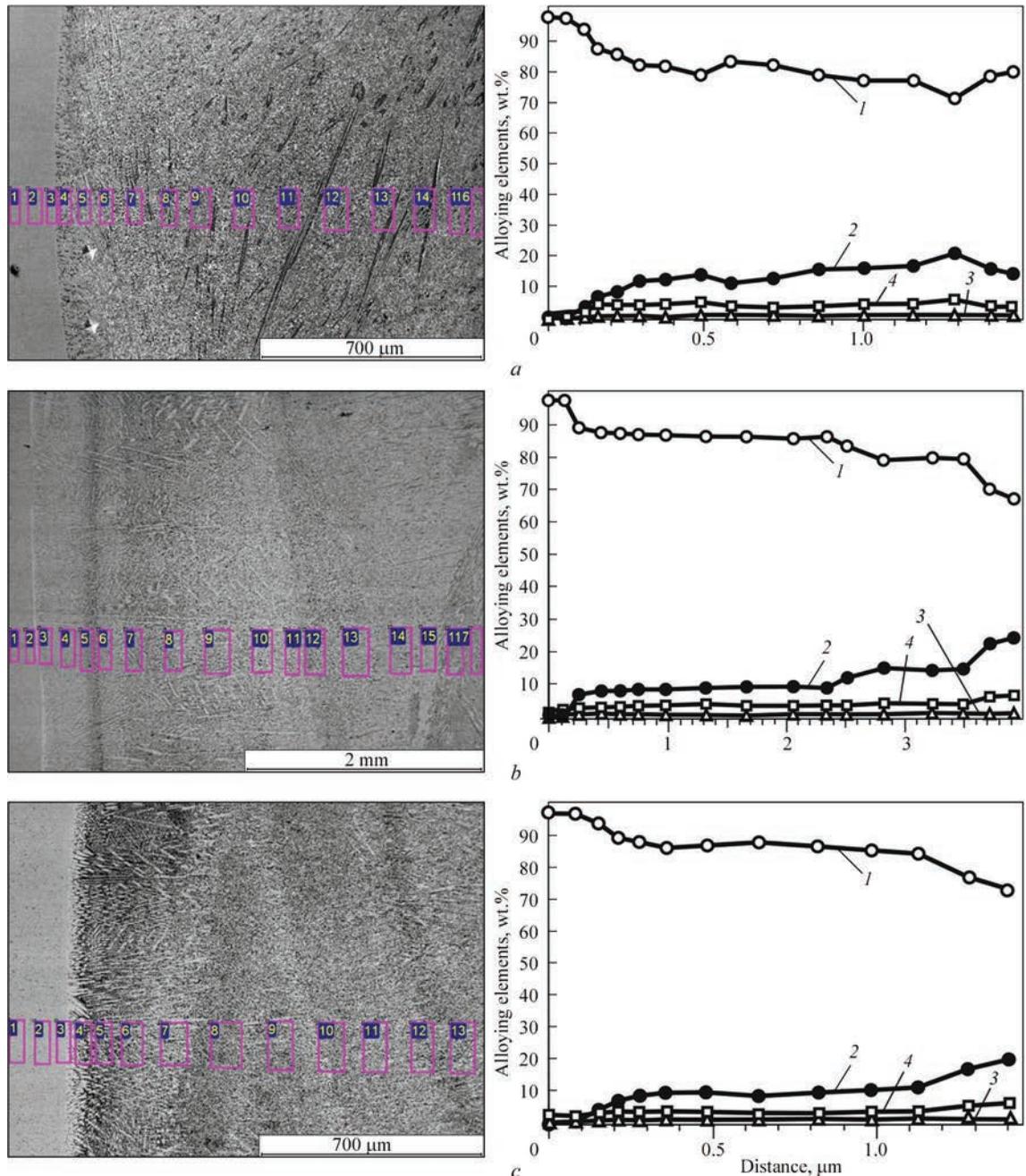
### EXPERIMENTAL INVESTIGATIONS AND THEIR RESULTS

Flux-cored strips of 16.5×4.0 mm cross-section with different content of chromium and ferrochrome were prepared for experiments:

- sample 1 – 50 % chromium carbide + 50 % FeCr;
- sample 2 – with Cr carbide, but without FeCr;
- sample 3 – with FeCr, but without chromium carbide.

Here, other charge components remained unchanged.

Surfacing was conducted in two layers to eliminate the influence of base metal in the deposited metal



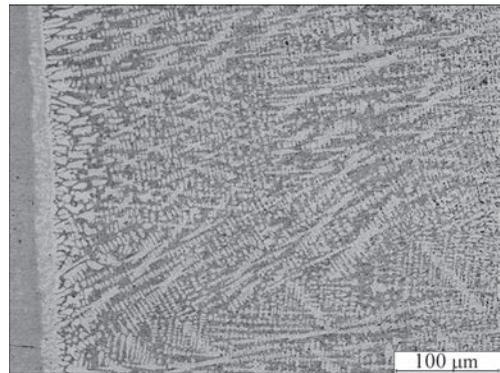
**Figure 1.** Distribution of alloying elements by deposited layer height: *a* — sample No.1; *b* — 2; *c* — 3 (*1* — iron; *2* — chromium; *3* — molybdenum; *4* — carbon)

working zone. Depending on the composition of the charge used, the ratio of phase components changed, and, thus the integral hardness of the deposited metal near the fusion line in the first and second layer. Carbide dimensions and orientation were also studied. In samples No.1 the volume fraction of the carbides is equal to 63–65 vol.%, integral hardness by the deposited layer height is 5400, 8100, and 9500 MPa, respectively, form factor is 1.32, the carbides are disoriented. Carbide orientation is of lanceolate shape, predominantly directed along the heat dissipation line; carbides are of a hexagonal shape disoriented. In samples No.2 the volume fraction of carbides is 85–90 vol.%, integral hardness is 6100; 7200 and 10800 MPa, form factor is 3.57, carbides are predominantly located along the heat dissipation line. In samples No.3 the carbide volume fraction is equal to 40–45 %, integral hardness by deposition height is 5620; 6860 and 7100 MPa, respectively, form factor is equal to 1.19, carbides of lanceolate shape are oriented predominantly along the heat dissipation line, those of hexagonal shape are disoriented. Form factor grows at increase of chromium carbide content in the flux-cored strip charge.

Figure 1 shows the curves of alloying element distribution by the deposited layer height, which correspond to a change of integral hardness.

An optimum combination of the deposited layer wear resistance and toughness is determined by the type and quantity of the carbide phase, its orientation, as well as matrix structure. At an anomalously large fraction of the carbide phase and coincidence of its orientation with the direction of the abrasive flow, the deposited metal wear resistance decreases, as “washing out” of the carbide component from the matrix takes place which is depleted in alloying elements.

Conducted investigations showed that the transition zone along the line of fusion with the first layer of the deposited metal in all the cases is characterized by formation of the solid solution dendrites and carbide eutectics in the interdendritic space. Dimensions of the zone with dendritic form of crystallization vary as follows: 50–370  $\mu\text{m}$  in sample No.1, 40–120  $\mu\text{m}$  in



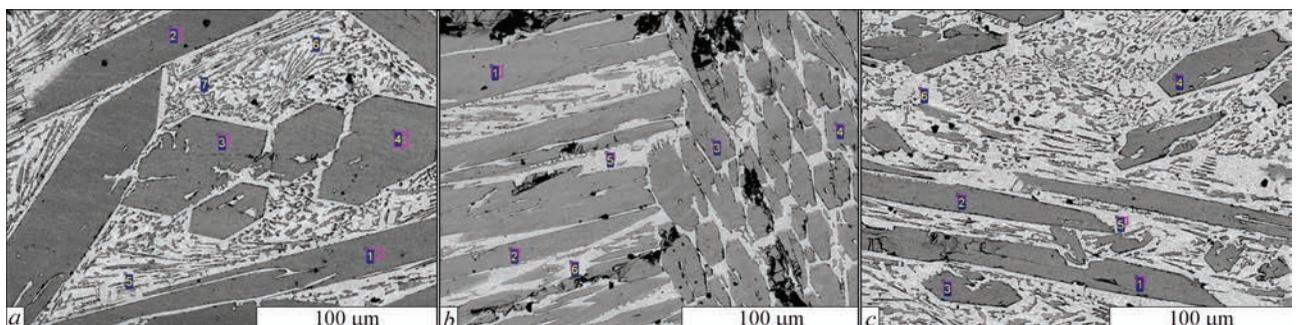
**Figure 2.** Typical structure of base metal — deposited layer transition zone

sample No.2 and 60–308  $\mu\text{m}$  in sample No.3. Typical structure of base metal – deposited layer transition zone of all the studied samples is shown in Figure 2.

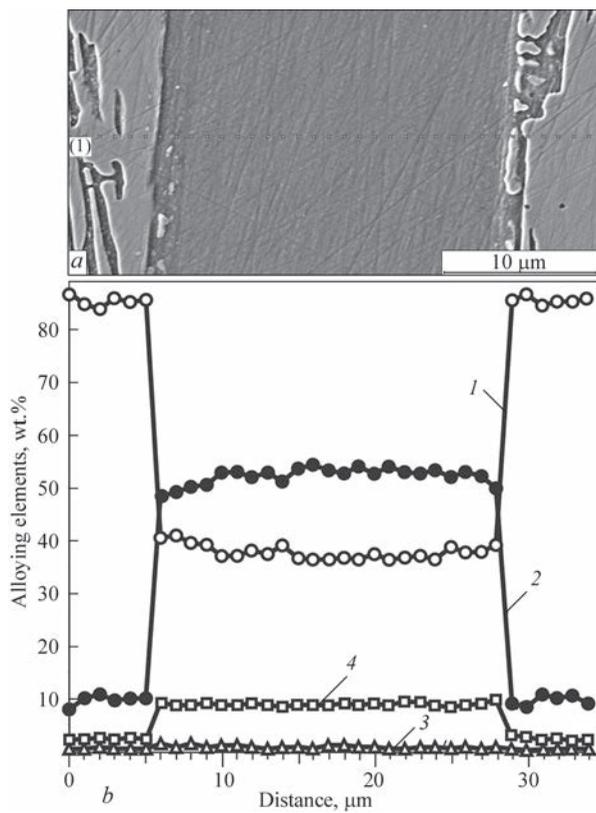
The method of X-ray structural analysis was used to determine the quantitative phase composition, type and parameters of the deposited metal crystalline lattice. The structure of the studied types of the deposited metal is an austenitic matrix and carbide phase of  $\text{Cr}_7\text{C}_3$ , as well as carbides with somewhat changed parameters, that suggests complex alloying of the carbide, the formula of which is similar to the calculation formula  $(\text{Cr}_{2.5}\text{Fe}_{4.3}\text{Mo}_{0.2})\text{C}_3$  from the international base of crystallographic data Pcpdfwin [11]. No Mo carbides were found. It is obvious that independent carbides do not form at Mo addition to the alloy in the quantity of approximately 1 %, and molybdenum liquates into Cr carbides.

The method of X-ray microanalysis was used to conduct investigations of alloying element distribution in the structural components and to determine their chemical composition. At transition from the first to the second layer of the deposited metal the nature of structure formation changes: the second layer structure is an austenitic matrix with carbides of different shape and orientation with their gradual coarsening towards the deposited metal surface.

A typical structure of the deposited metal second layer in sample No.1 is given in Figure 3, *a*, and chemical composition of its phase components — in Table 1; that of sample No.2 — in Figure 3, *b* and



**Figure 3.** Sample microstructure: No.1 (*a*), No.2 (*b*), No.3 (*c*)

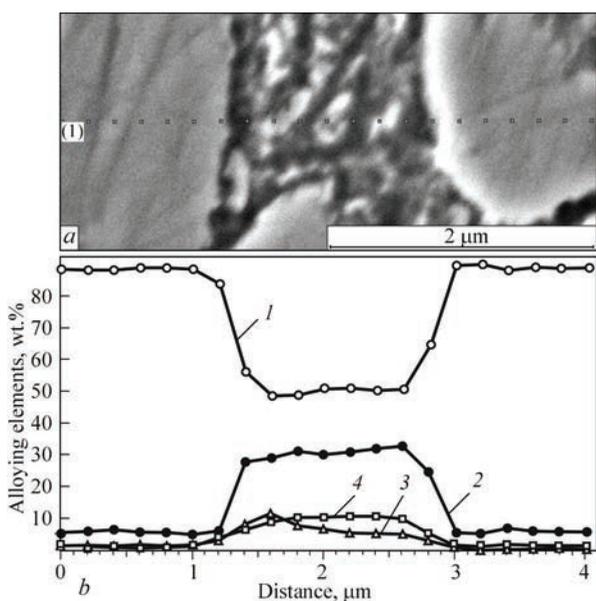


**Figure 4.** Structure (a) and distribution of alloying elements in  $(FeCr)_7C_3$  carbide (b): 1 — iron; 2 — chromium; 3 — molybdenum; 4 — carbon

in Table 2; of sample No.3 — in Figure 3, c and in Table 3.

**DISCUSSION OF THE RESULTS**

Presented data demonstrate reduction of the carbide-forming element in the austenitic component of the deposited metal, depending on the composition of the charge, used at surfacing.



**Figure 5.** Structure (a) and distribution of alloying elements in  $(Cr_{2.5}Fe_{4.2}Mo_{0.2})C_3$  carbide (b): 1 — iron; 2 — chromium; 3 — molybdenum; 4 — carbon

**Table 1.** Weight fraction of elements in the points of analysis of sample No.1

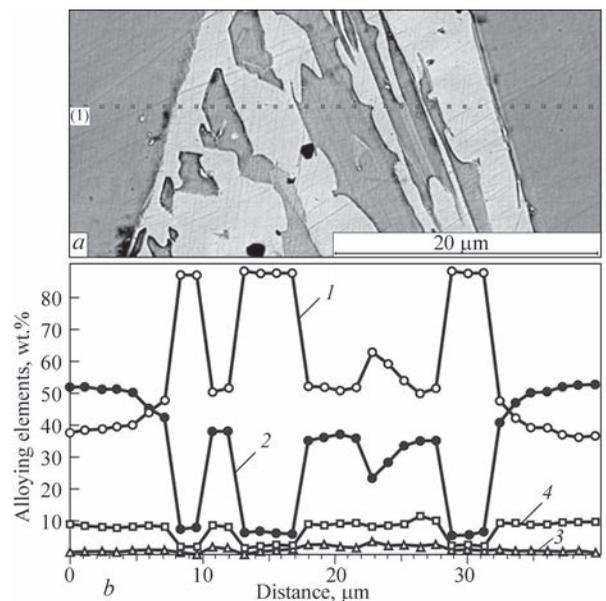
Analysis point	C	Al	Si	Cr	Fe	Mo	Total
1	8.94	0.04	0.02	53.56	36.35	1.08	100.00
2	9.23	0.00	0.00	51.37	38.59	0.81	100.00
3	9.00	0.02	0.01	53.75	36.42	0.80	100.00
4	9.16	0.05	0.00	53.66	36.23	0.89	100.00
5	3.16	1.12	0.75	8.75	85.45	0.78	100.00
6	2.58	1.00	0.77	9.75	85.57	0.34	100.00
7	2.11	0.59	0.83	8.15	86.87	1.44	100.00

**Table 2.** Weight fraction of elements in points of analysis of sample No.2

Analysis point	C	Al	Si	Cr	Fe	Mo	Total
1	8.87	0.00	0.09	53.73	36.38	0.93	100.00
2	8.91	0.00	0.04	53.35	36.81	0.88	100.00
3	9.04	0.04	0.00	54.76	35.39	0.77	100.00
4	9.11	0.05	0.03	54.91	35.18	0.72	100.00
5	2.11	1.31	1.15	7.28	87.10	1.04	100.00
6	2.30	1.32	0.92	7.78	86.62	1.06	100.00

**Table 3.** Weight fraction of elements in points of analysis of sample No.3

Analysis point	C	Al	Si	Cr	Fe	Mo	Total
1	9.28	0.02	0.04	53.24	36.02	1.40	100.00
2	8.80	0.00	0.01	52.27	38.16	0.75	100.00
3	8.73	0.00	0.05	52.63	37.49	1.10	100.00
4	9.22	0.01	0.00	52.88	36.80	1.10	100.00
5	2.12	0.65	0.60	11.98	83.89	0.75	100.00
6	2.23	0.69	0.64	10.27	85.16	1.01	100.00



**Figure 6.** Structure (a) and distribution of alloying elements in the deposited metal structural components (b): 1 — iron; 2 — chromium; 3 — molybdenum; 4 — carbon

Hardness in structural components ( $P = 100$  g) in the studied types of the deposited metal practically does not change: Aus + fine C — 6100–6700 MPa (it is practically impossible to separate austenite and dispersed carbides); hardness of lanceolate carbides — 16500–16800 MPa, of those of hexagonal shape — approximately 11500–11800 MPa.

The composition and degree of alloying of (Fe-Cr)<sub>7</sub>C<sub>3</sub> carbides was determined, wt.%: 8.9–9.1 C; 52–53 Cr; 37.2–38.5 Fe; 0.2 Mo, and of those of another composition, wt.%: 9.5 C; 31.5–32.0 Cr; 50.8–52.0 Fe; 2.8–6.0 Mo that practically confirms presence of a carbide, described by (Cr<sub>2.5</sub>Fe<sub>4.2</sub>Mo<sub>0.2</sub>)C<sub>3</sub> formula. Figures 4 and 5 also show typical curves of linear distribution of alloying elements in (FeCr)<sub>7</sub>C<sub>3</sub> and (Cr<sub>2.5</sub>Fe<sub>4.2</sub>Mo<sub>0.2</sub>)C<sub>3</sub> carbides. It should be noted that (Cr<sub>2.5</sub>Fe<sub>4.2</sub>Mo<sub>0.2</sub>)C<sub>3</sub> carbide is heterogeneous by its structure (sample No.1).

Hard wear-resistant alloys are heterogeneous by their structure. Figure 6 (sample No.2) shows typical curves of alloying element distribution in the deposited metal structural components, which demonstrate the heterogeneity of the structure and composition of phase components, and clearly show the diffusion-induced redistribution of alloying elements in the zone of transition from the matrix to the carbide.

## CONCLUSIONS

Investigations showed that the optimum concentration of the carbide phase in the metal, deposited with flux-cored strip of PL-AN180 type, is achieved due to adding carbide-forming element — chromium to the electrode material charge in the proportion of 15–25 % chromium carbide and 75–85 % proportion of ferrochrome. Complex carbides of (CrFe)<sub>7</sub>C<sub>3</sub> system are mainly present in the deposited metal for all the samples. Molybdenum does not form separate carbide compounds, but is a component in carbides of (Cr<sub>2.5</sub>Fe<sub>4.2</sub>Mo<sub>0.2</sub>)C<sub>3</sub> type.

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## CONFLICT OF INTEREST

The Authors declare no conflict of interest

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