

# INFLUENCE OF THE COMPOSITION OF CHARGE COMPONENTS OF FLUX-CORED STRIPS OF C–Fe–Cr–Nb ALLOYING SYSTEM ON CHEMICAL COMPOSITION AND STRUCTURE OF THE DEPOSITED METAL

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## ABSTRACT

It is common knowledge that wear resistance of the deposited chromium carbide layer, additionally alloyed by such carbide-forming elements, as molybdenum, niobium, etc., largely depends on the reinforcing phase characteristics, its concentration, and properties of matrix alloy. Good performance of such alloys under the conditions of abrasive wear at up to 600 °C temperatures is achieved by adding niobium to the alloy composition. This work is a study of charge components of flux-cored strips of C–Fe–Cr–Nb alloying system on the deposited metal composition and properties. The methods of X-ray diffraction, metallographic and X-ray microprobe analysis of metal of 500Kh22B7 type deposited by flux-cored strips, revealed the dependence of concentrations, shape, orientation, phase components and integral hardness of the deposited layer on the form of addition of the main carbide-forming element, namely chromium, to the charge and flux-cored strip cross-section. It was found that at addition of chromium carbide  $\text{Cr}_3\text{C}_2$  to the flux-cored strip charge, carbide phase concentration in the deposited layer increases by 10 %. Complex carbides of  $(\text{Cr}, \text{Fe})_7\text{C}_3$  system are predominantly present in the deposited metal for all the samples. Niobium forms individual carbide components of much smaller dimensions, compared to complex chromium carbide. Optimal concentration of the carbide phase in the metal of 500Kh22B7 type deposited by flux-cored strip is achieved by addition of a carbide-forming element, namely chromium, to the electrode material charge, in the form of chromium carbide and ferrochromium. Flux-cored strip cross-section and surfacing modes practically do not affect the deposited layer properties.

**KEYWORDS:** flux-cored strip, chromium carbide, ferrochromium, niobium, carbides, hardness, microstructure, matrix, concentration

## INTRODUCTION

Many parts of metallurgical equipment operate under the conditions of abrasive and gas-abrasive wear at normal and higher temperatures in combination with impact loads [1–3, etc.]. Selection of the alloy type for surfacing such parts is determined by the possibilities of surfacing some items, financial possibility, as well as the nature of loading, particularly in combination of abrasive wear and shock at increased (up to 600 °C) temperatures [4]. For substantiated alloying of wear-resistant alloys it was necessary to establish rational alloying limits, which would provide optimal properties of the deposited layer [5–7]. Studying the relation between alloy wear resistance and carbide phase structure, as well as between the regularity of carbide formation and alloy chemical composition is the most important for rational alloying of the materials. It is known that alloys having high hardness carbides with cubic lattice in their composition demonstrate the highest wear resistance [8–10, etc.]. However, deposited metal with carbides and with a different crystalline lattice, for instance hexagonal, also has a satisfactory wear resistance. For one and

the same carbide type, its properties will somewhat differ, depending on alloying. So, metal with carbides of  $\text{Me}_7\text{C}_3$  type, containing a large quantity of iron, will differ by their wear resistance from metal of carbides of the same type, but with a smaller quantity of iron. Note that carbide hardness depends on the degree of their alloying that, in its turn, influences the deposited metal wear resistance. Kinetics of carbide formation at metal solidification is related to the value of  $\text{Me}/\text{C}$  (metal/carbon) ratio. In the presence of several carbide-forming elements in the deposited metal carbides of elements with the highest affinity to carbon are the first to form.

The objective of this work is studying the influence of carbide-forming components of the charge of PL-AN185 flux-cored strip, electrode material cross-section, and influence of surfacing modes on the structure and phase components of the deposited metal to produce a coating resistant to abrasive and gas-abrasive wear at higher temperatures.

## INVESTIGATION PROCEDURE AND EQUIPMENT

The methods of X-ray diffraction, metallographic and X-ray microspectral analyses were used to study the

deposited metal of 500Kh22B7 type. Hardness measurements were conducted in M-400 microhardness meter of Leco Company, JAMP-950F and DRON-UM1 instruments were used for X-ray spectral, electron microscopy and X-ray diffraction investigations. Microstructural studies were performed in Neophot-32 microscope.

Sample surfacing was performed by electric arc process using PL-AN185 self-shield flux-cored strip that ensures producing deposited metal of the following chemical composition, wt.%: 4.5 C; 22 Cr; 7 Nb. Surfacing was performed by flux-cored strips of 16.5×40 mm (samples Nos 1, 3) and 10.0×3.0 mm cross-section (sample No. 2). PL-AN185 flux-cored strip was used for surfacing wear-resistant bimetal plates from 5 to 30 mm thick and other parts of metallurgical, power and mining equipment [11].

In C-Fe-Cr-Nb alloying system the reinforcing phase is the present predominantly chromium and niobium carbides, and the matrix is an iron-based alloy. It is important to determine how the concentration of carbides and other deposited layer characteristics are influenced by the method of addition of the main carbide-forming component, namely chromium to the flux-cored strip charge. High-carbon ferrochromium of FKh900 grade (sample No. 3) and chromium carbide in other samples were used to add chromium. The latter by its chemical composition is close to the stoichiometry of  $Cr_3C_2$  carbide. Niobium was added to the flux-cored strip charge using ferroniobium. Moreover, graphite and other technological fillers were further added to the charge composition.

## EXPERIMENTAL STUDIES AND THEIR RESULTS

Experimental studies were conducted on samples of metal of 500Kh22B7 type, deposited by a strip with a standard charge from chromium carbide, produced in different modes:  $I_w \sim 750\text{--}850$  A (sample No. 1),  $I_w \sim 450\text{--}500$  A (sample No. 2), sample No. 3 was produced using electrode strip with high-carbon ferrochromium of FKh900 grade in the following mode:  $I_w \sim 750\text{--}850$  A. Here, other charge components remained unchanged. Table 1 gives the average composition in the samples of the deposited metal type.

Surfacing was performed in two layers as at two-layer surfacing with the strips the influence of

base metal (first layer) decreases and the working zone (second layer) forms only under the influence of the flux-cored strip material.

The weight fraction of phase components, type of crystalline lattice and its parameters were assessed by the method of X-ray diffraction analysis:  $\gamma\text{-Fe} - 54.4$ ;  $(Fe, Cr)_7C_3 - 22.3$ ;  $NbC - 17.3$ ;  $Me_2C - 6.0$  (sample No. 1);  $\gamma\text{-Fe} - 57.2$ ;  $(Fe, Cr)_7C_3 - 23.2$ ;  $NbC - 15.7$ ;  $Me_2C - 3.8$  (sample No. 2);  $\gamma\text{-Fe} - 65.7$ ;  $(Fe, Cr)_7C_3 - 16.0$ ;  $NbC - 15.9$ ;  $Me_2C - 2.4$  wt.% (sample 3). When producing this type of the deposited metal, the matrix structure is of great importance, as austenitic matrix is more appropriate at high loads and presence of impact action. Structure of the studied samples in the transition zone (first layer of the deposited metal) is an austenitic matrix with dendrite-cellular form of crystallization, niobium carbides and eutectic which precipitated on the boundaries of dendrites and cells. The working zone structure (second layer of the deposited metal) of all the studied samples is an alloyed austenitic matrix with dendritic-cellular form of crystallization. In samples No. 1 and 2 alloyed  $(Fe, Cr)_7C_3$  and  $NbC$  carbides of lancet-like shape 20–25  $\mu\text{m}$  long are chaotically arranged over the entire plane. The nature of crystallization of sample No. 3 in the working layer is somewhat different – the carbides are more dispersed, their size is 2–8  $\mu\text{m}$ , and they are located along the cell boundaries.

Comparative analysis of surfaced samples Nos 1 and 2, produced in different modes (by wide strip at  $I_w = 750$  A and by narrow strip at  $I_w = 450$  A), showed that the weight fraction of the austenitic component is equal to 54.5 wt.% at  $I_w = 750$  A and 57.2 wt.% at  $I_w = 450$  A, and at the same modes ( $I_w = 750$  A) for samples No. 1 (standard charge with chromium carbide) and 3 (charge with high-carbon ferrochromium of FKh900 grade) the austenitic component of sample No. 3 is equal to 65.7 wt.%. In this case, the carbide component decreases approximately by 10 %. Integral hardness in the working layer of samples Nos 1–3 is equal to 6868; 6870 and 5490 MPa, respectively.

Table 2 gives the average composition of alloying elements of the solid solution of deposited metal (samples Nos 1–3) and its carbide components. Chemical composition of the solid solution and niobium carbides of the three samples practically does not change, and the degree of alloying of (Fe,

**Table 1.** Average chemical composition of deposited metal 500Kh22B7, wt.%

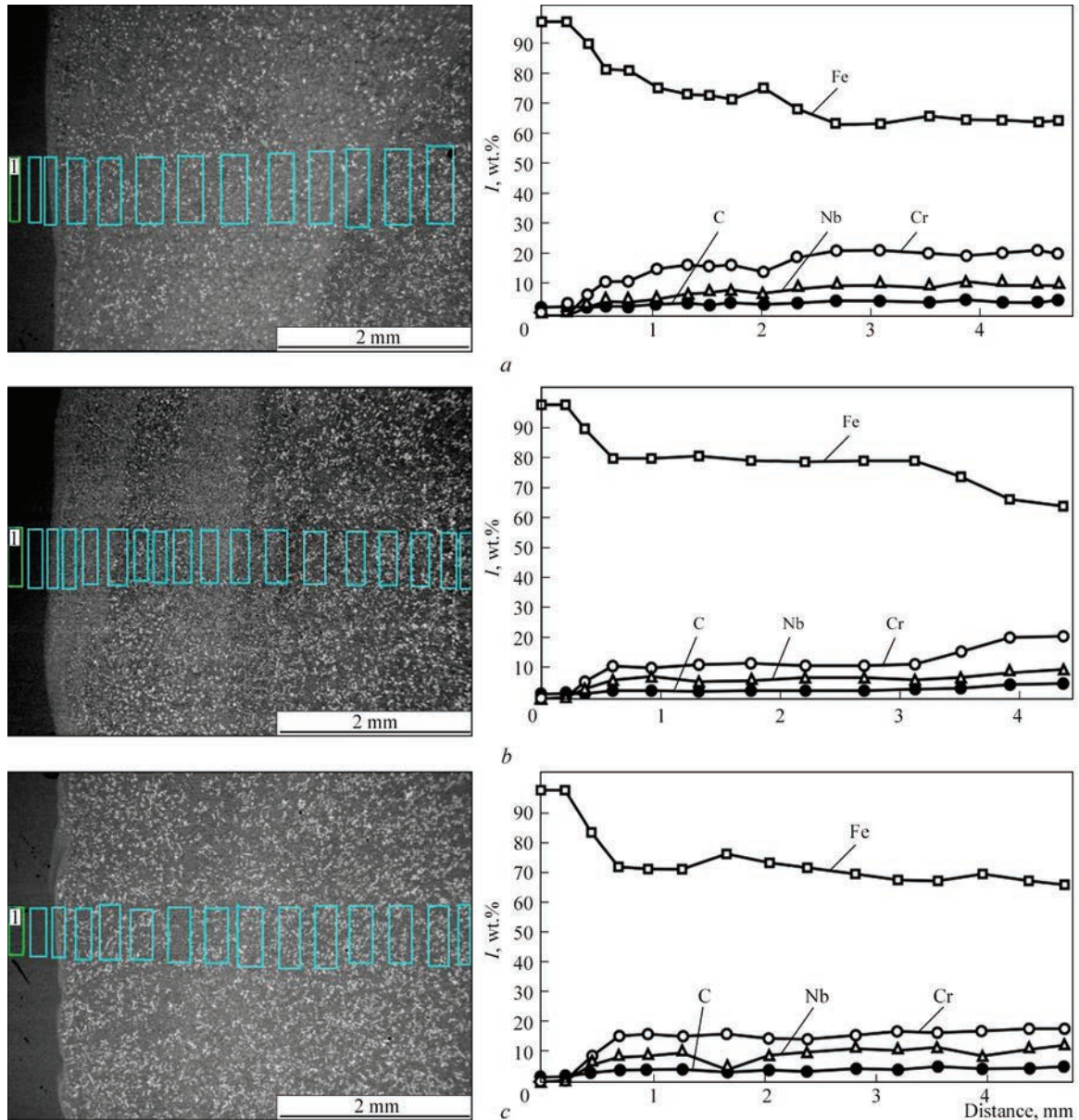
Sample number	C	Si	Mn	Cr	Ni	Mo	Nb	Fe
1	4.8	1.04	0.29	24.6	≤0.1	0.086	7.3	Base
2	4.7	1.02	0.49	24.4	≤0.1	0.057	7.2	
3	4.5	1.02	0.47	19.6	≤0.1	0.089	8.6	

**Table 2.** Chemical composition of the solid solution and carbide phases of deposited metal of 500Kh22B7 type, wt.%

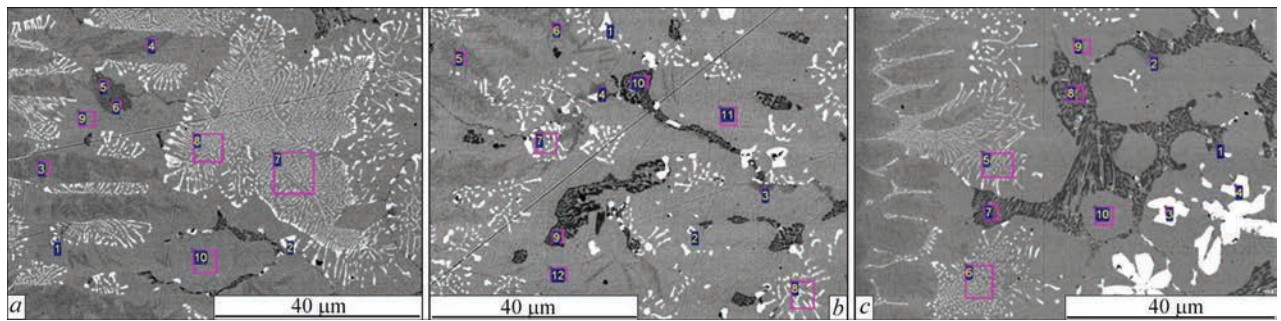
Sample number	Working zone solid solution				(Cr, Fe) <sub>7</sub> C <sub>3</sub> and NbC carbides				Carbide type
	C	Fe	Cr	Nb	C	Fe	Cr	Nb	
1	1.17	82.50	14.35	0.85	8.62	32.90	57.80	0.45	(Fe, Cr) <sub>7</sub> C <sub>3</sub>
					11.20	1.20	1.19	85.60	NbC
2	1.25	82.70	13.90	0.30	8.64	32.70	58.00	0.44	(Fe, Cr) <sub>7</sub> C <sub>3</sub>
					11.40	0.95	2.25	84.20	NbC
3	1.70	82.02	13.45	0.20	8.55	48.60	41.60	0.25	(Fe, Cr) <sub>7</sub> C <sub>3</sub>
					10.80	1.28	1.65	84.80	NbC

Cr)<sub>7</sub>C<sub>3</sub> carbides, located in the eutectic along the cell boundaries in sample No. 3 (without addition of chromium carbide to the charge, with its replacement by high-carbon ferrochromium), is somewhat different from that of the same type of carbides in samples Nos 1 and 2.

Integral hardness in height of the deposited layer changes gradually from the base metal to its surface in the range from 3700 to 6700–6900 MPa (samples Nos 1, 2) and from 3800 to 5400 MPa (sample No. 3), and it is leveled in the second layer of the deposited metal that corresponds to the change of chemical



**Figure 1.** Electronic image and linear distribution of alloying elements in the deposited layer height: *a-c* — samples Nos 1–3, respectively



**Figure 2.** Electronic image of structural components of the deposited metal transition zone: *a-c* — samples Nos 1–3

composition on integral curves of linear distribution of alloying elements. The zone of fusion with the base metal has a smooth concentrational transition with further leveling of the chemical composition in the working zone. Linear distribution of alloying elements in the deposited layer height is shown in Figure 1. Chemical composition of the deposited layer along the line of electronic probe passage can be determined by the concentration scale.

Structure of crystallization of the transition zone of base metal–deposited layer is dendritic-cellular with eutectic precipitates in interdendritic areas on the cell boundaries and separate precipitates of niobium carbides. Two kinds of eutectic are observed — based on niobium carbide and on  $(Fe, Cr)_7C_3$  carbides. Electronic image of the transition zone of base metal–de-

**Table 3.** Average chemical composition of the solid solution and eutectic formations of sample No. 1. Treatment parameters, wt. %

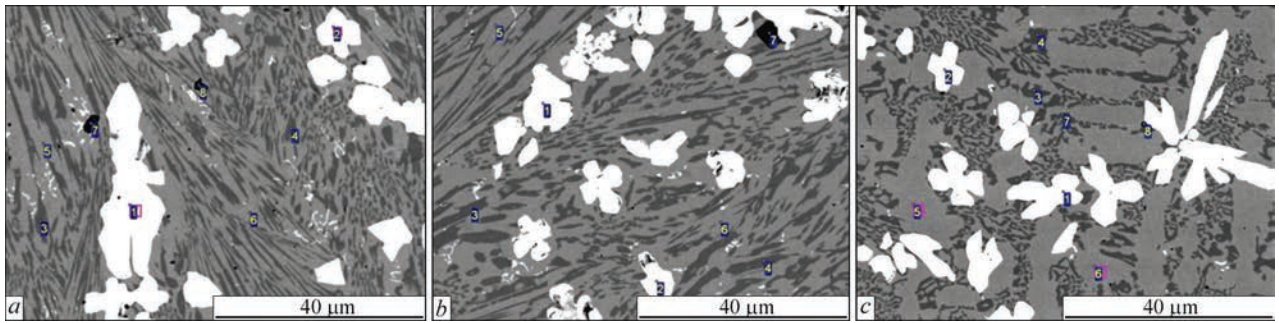
Spectrum number	C	Cr	Fe	Nb
1	11.87	1.28	3.64	83.07
2	11.51	3.96	18.89	65.45
3	1.30	6.72	90.55	0.55
4	1.42	7.16	90.20	0.41
5	2.61	12.00	84.45	0.24
6	2.63	12.91	83.72	0.00
7	2.06	8.60	81.63	6.96
8	2.52	8.34	80.17	8.27
9	1.90	9.38	87.72	0.18
10	1.37	8.82	88.69	0.20

**Table 4.** Average chemical composition of the solid solution and eutectic formations of samples No. 2. Treatment parameters, wt. %

Spectrum number	C	Si	Cr	Mn	Fe	Nb
1	9.76	0.00	1.69	0.77	2.67	83.67
2	11.44	0.05	1.85	0.18	3.39	82.61
3	2.10	0.44	8.71	1.22	86.78	0.42
4	2.40	0.48	8.21	1.69	86.62	0.11
5	1.39	0.43	5.49	0.92	91.41	0.28
6	1.74	0.42	6.39	0.91	89.87	0.55
7	2.94	0.53	6.50	0.95	77.81	11.10
8	2.66	0.51	8.30	1.06	74.98	12.01
9	5.25	0.29	25.71	1.05	67.68	0.00
10	5.29	0.24	24.76	1.71	67.17	0.67
11	1.28	0.37	7.33	1.41	88.93	0.35
12	1.34	0.45	7.36	1.72	88.73	0.00

**Table 5.** Average chemical composition of the solid solution and eutectic formations of sample No. 3. Treatment parameters, wt. %

Spectrum number	C	Si	Cr	Fe	Nb
1	2.20	0.69	8.88	87.82	0.00
2	2.36	0.72	9.53	86.63	0.23
3	11.30	0.01	1.80	2.46	83.68
4	1.19	0.03	1.44	2.57	83.87
5	2.33	0.36	7.21	81.99	7.81
6	2.12	0.41	6.90	82.50	7.63
7	5.36	0.38	26.65	67.24	0.16
8	5.21	0.26	24.90	68.89	0.60
9	1.39	0.49	10.19	87.34	0.14
10	1.52	0.54	9.57	87.15	0.62



**Figure 3.** Electronic image of structural components of the deposited metal working zone: *a–c* — samples Nos 1–3, respectively

posited layer and average chemical composition of the structural components are shown in Figure 2 and in Tables 3–5.

Base metal influence in the transition zone and in first layer of the deposited metal is practically the same.

Deposited metal structures in the working zone (second layer), its electronic image and chemical composition of the structural components are shown in Figure 3, *a–c* and in Tables 6–8. Spectrum Nos 1,

2 is NbC; spectrum 3, 4 is  $(\text{Fe}, \text{Cr})_7\text{C}_3$ ; spectrum 5, 6 is the solid solution. A change of structure formation in samples No. 1 and 3 is found, depending on the change of the charge composition.

Distribution of alloying elements by the structural components in the deposited metal of the second layer is shown in Figure 4. Such structural components of the deposited metal with formation of carbides of a high hardness promote a considerable improvement of the quality of products operating under abrasive

**Table 6.** Chemical composition of structural components of the working zone (second layer) of sample No. 1. Treatment parameters, wt.%

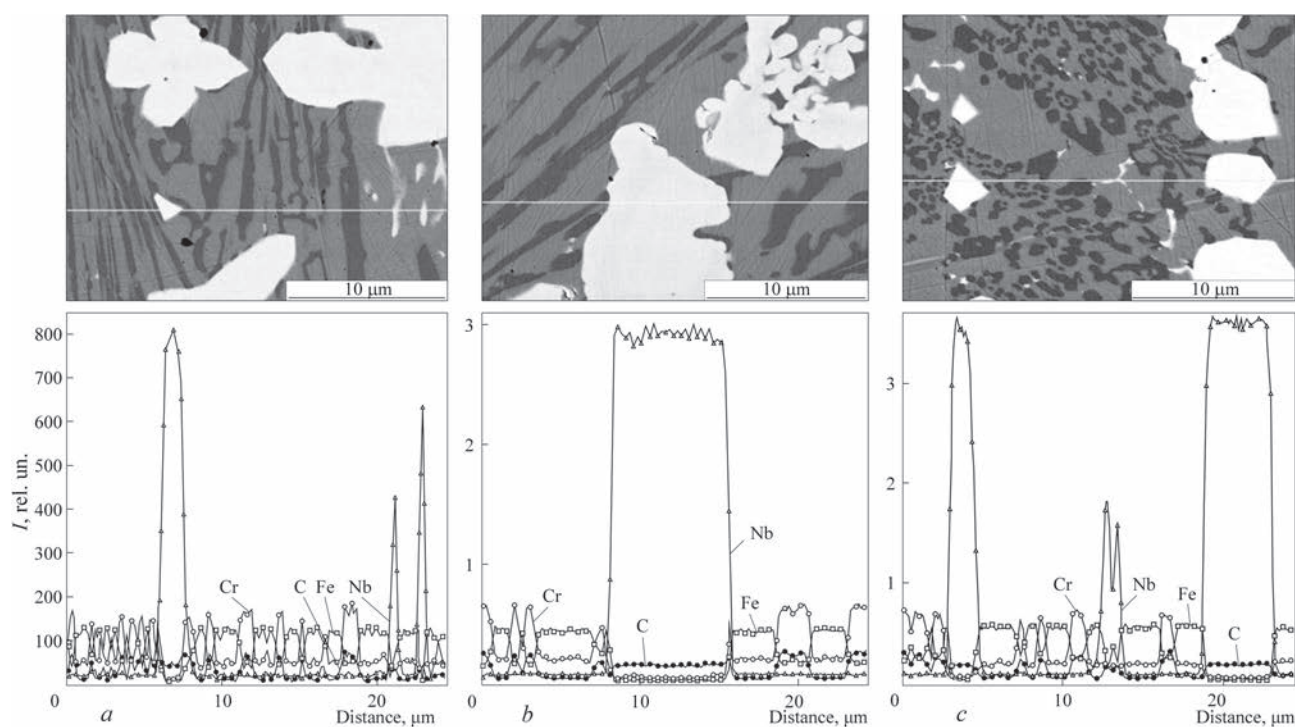
Spectrum number	C	Si	Cr	Fe	Nb
1	11.56	0.10	0.75	1.34	85.30
2	10.80	0.04	1.60	1.04	85.66
3	8.53	0.00	58.21	32.61	0.56
4	8.70	0.00	57.38	33.17	0.40
5	1.12	0.96	15.22	81.66	0.41
6	1.22	1.25	13.50	83.37	0.17
7	1.12	0.12	0.64	2.10	0.00
8	1.16	0.12	0.73	1.70	0.30

**Table 7.** Chemical composition of structural components of the working zone (second layer) of sample No. 2. Treatment parameters, wt.%

Spectrum number	C	Si	Cr	Fe	Nb
1	11.21	0.08	2.44	0.54	84.45
2	11.67	0.02	2.18	1.30	83.89
3	8.70	0.00	58.59	31.93	0.72
4	8.58	0.06	57.57	33.35	0.17
5	1.26	1.11	14.12	82.54	0.21
6	1.42	1.15	13.70	82.95	0.13
7	–	0.35	3.08	11.80	1.89

**Table 8.** Chemical composition of structural components of the working zone (second layer) of sample No. 3. Treatment parameters, wt.%

Spectrum number	C	Si	Cr	Mn	Fe	Nb
1	10.89	0.00	1.33	0.55	0.95	85.00
2	10.68	0.10	1.97	0.00	1.60	84.04
3	8.67	0.06	49.19	0.00	41.28	0.31
4	8.29	0.02	48.02	1.07	41.91	0.24
5	1.87	0.91	13.06	0.78	82.03	0.00
6	1.65	1.05	13.23	0.27	82.07	0.20
7	–	0.09	4.55	7.62	5.99	0.00
8	–	0.00	0.81	1.68	2.28	0.00



**Figure 4.** Linear distribution of C, Fe, Cr, Nb alloying elements by deposited metal structural components: *a-c* — samples Nos 1–3, respectively

wear conditions. At comparison of samples produced in different modes (Nos 1, 2) and in one mode, but with different composition of the charge (Nos 1, 3) may lead to the conclusion that weight fraction in the working zone increases from sample No. 1 to sample No. 3 by approximately 10–12 wt.%, and weight fraction of the carbide phase decreases. There is a change in structure formation: in samples Nos 1 and 2 the structure is an austenitic matrix with chaotically located Cr and Nb carbides of different shape. In sample No. 3 the crystallization structure is dendritic-cellular with  $(\text{Fe, Cr})_7\text{C}_3$  carbides in the composition of the eutectic located on the cell boundaries and in the interdendritic space, and with niobium carbides of a different shape, randomly located in the entire height of the deposited layer. The degree of carbide alloying in samples Nos 1 and 2 is the practically the same, and in sample No. 3 it is somewhat higher (see Table 2).

## DISCUSSION OF THE RESULTS

From the presented data, there is a decrease of the carbide component in absence of chromium carbide in the charge composition.

The weight fraction of phase components, crystalline lattice type and its parameters were determined, which were assessed by the method of X-ray diffraction analysis:  $\gamma\text{-Fe}$  – 54.4;  $(\text{Fe, Cr})_7\text{C}_3$  – 22.3; NbC – 17.3;  $\text{Me}_2\text{C}$  – 6.0 wt.% (surfacing with a strip of 16.5×4.0 mm cross-section);  $\gamma\text{-Fe}$  – 57.2;  $(\text{Fe, Cr})_7\text{C}_3$  – 23.2; NbC – 15.7;  $\text{Me}_2\text{C}$  – 3.8 wt.% (surfacing with a strip of 10.0×3.0 mm cross-section in lower

modes);  $\gamma\text{-Fe}$  – 65.7;  $(\text{Fe, Cr})_7\text{C}_3$  – 16.0; NbC – 15.9;  $\text{Me}_2\text{C}$  – 2.4 wt.% (complex carbide, containing iron and other carbide-forming elements, surfacing with flux-cored strip of 16.5×4.0 mm cross-section with chromium carbide replacement by high-carbon ferrochromium in the charge composition).

Integral hardness in height of the deposited layer changes gradually from base metal to the hardened layer surface in the range from 3700 to 6700–6900 MPa (samples Nos 1, 2) and from 3800 to 5400 MPa (sample No. 3) and it is leveled in the second layer of the deposited metal that corresponds to the change of chemical composition in integral curves of linear distribution of alloying elements.

Wear-resistant layer obtained using flux-cored strips of different cross-section and in different surfacing modes, practically does not differ by its characteristics. Replacement of chromium carbide by high-carbon ferrochromium in the charge composition reduces the amount of the carbide phase and integral hardness of hardened surface.

## CONCLUSIONS

It is found that optimum concentration of the carbide phase in the metal deposited by flux-cored strip of PL-AN185 type, is reached due to addition of carbide-forming element — chromium to the electrode material charge in the form of chromium carbide. Replacement of chromium carbide by high-carbon ferrochromium in the charge composition leads to increase of austenitic component and decrease of in-

tegral microhardness of the deposited layer. In the deposited metal complex carbide systems (Cr, Fe)<sub>7</sub>C<sub>3</sub> are predominantly present in all the samples. Niobium forms individual carbide components, which are uniformly arranged in the working zone and promotes formation of a finely-dispersed structure of the deposited layer.

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## CONFLICT OF INTEREST

The Authors declare no conflict of interest

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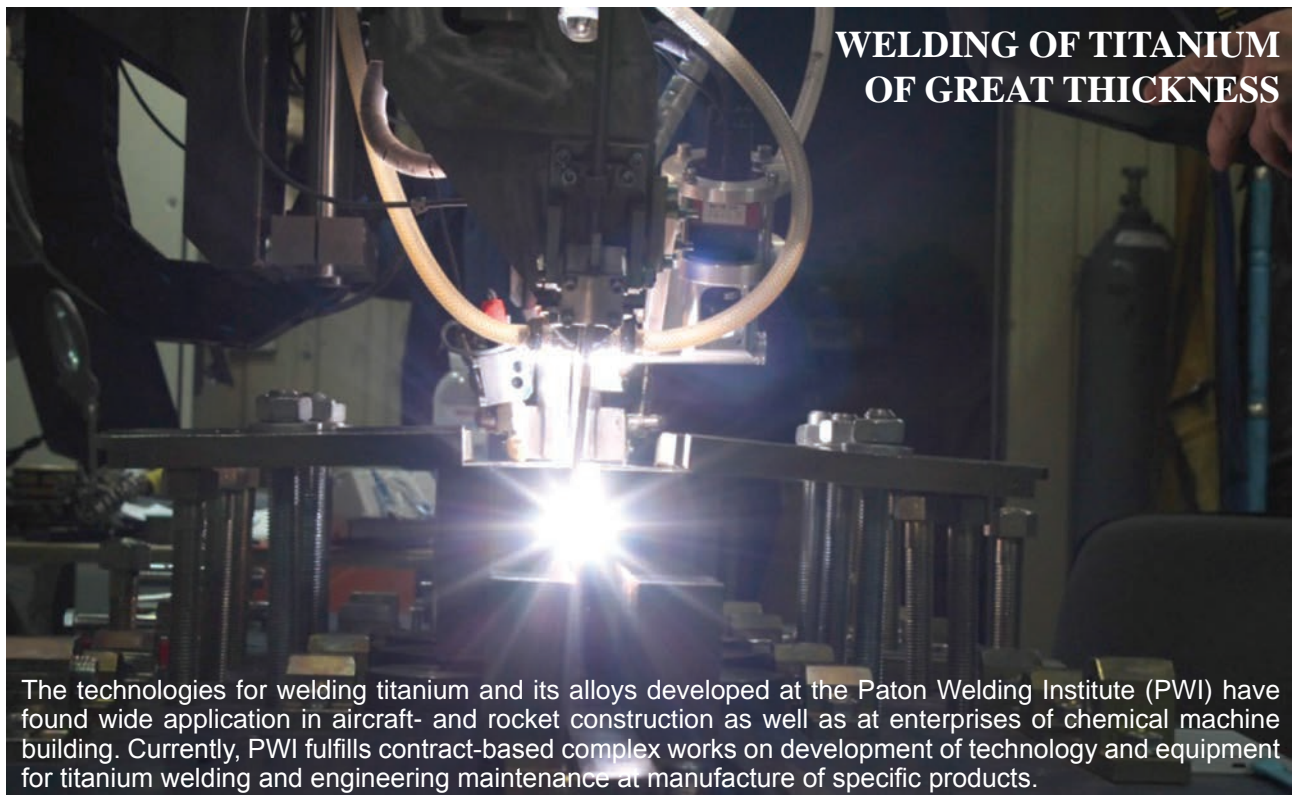
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## WELDING OF TITANIUM OF GREAT THICKNESS

The technologies for welding titanium and its alloys developed at the Paton Welding Institute (PWI) have found wide application in aircraft- and rocket construction as well as at enterprises of chemical machine building. Currently, PWI fulfills contract-based complex works on development of technology and equipment for titanium welding and engineering maintenance at manufacture of specific products.