

CHEMICAL AND THERMAL TREATMENT AND COATINGS

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INVESTIGATION OF THE MICROSTRUCTURE OF SURFACED LAYER FROM FLUX-CORED WIRE OF THE Fe – C – Si – Mn – Cr – Ni – Mo – V SYSTEM

I. V. Osetkovskiy,¹ A. M. Yunusov,² N. A. Kozyrev,³ A. R. Mikhno,³ and A. A. Komarov³Translated from *Metallovedenie i Termicheskaya Obrabotka Metallov*, No. 6, pp. 29 – 35, June, 2022.*Original article submitted December 30, 2021.*

The article presents the results of studies of the structure and non-metallic inclusions of metal surfaced from a flux-cored wire of the Fe – C – Si – Mn – Cr – Ni – Mo – V system. In the composition of the wire charge, instead of amorphous carbon, gas cleaning dust of aluminum production containing carbon and fluorine was introduced. Surfacing from a flux-cored wire with a diameter of 5 mm on plates made of St3 steel under AN-26S flux was carried out using a welding machine at a current of 420 – 520 A, a voltage of 28 – 32 V, a welding rate of 7.2 – 9 m/h with cooling at room temperature. The properties of two samples with different content of the carbon-fluorine-containing additive in a flux-cored wire have been studied. The grain size and martensite dispersion in the structure of the surfaced layer have been determined. The analysis of the chemical composition of the surfaced layer and non-metallic inclusions generated in it has been carried out. The hardness of the samples has been measured by the Rockwell method. It has been concluded that it is necessary to establish the optimal amount of the carbon-fluorine-containing additive in the flux-cored wire in order to avoid the formation of an increased amount of non-metallic inclusions in the surfaced layer.

Keywords: surfacing, flux-cored wire, alloying, microstructure, non-metallic inclusions, chemical composition.

INTRODUCTION

The properties of the surfaced metal, other things being equal, largely depend on the carbon content in it. An increase in the carbon content, on the one hand, increases the hardness and wear resistance of the surfaced layer; on the other hand, it reduces the weldability and the crack resistance of the surfaced metal layer [1].

Earlier, as part of developing the direction for improving the compositions of surfacing materials of the Fe – C – Si – Mn – Cr – Ni – Mo – V system in SibGIU, a new composition of flux-cored wire using a carbon-fluorine-containing

material and being the gas cleaning dust of aluminum production has been developed. The use of such a wire allows excluding the formation of pores, cavities, cracks and removing hydrogen in the surfacing [2 – 10]. The chemical composition of flux-cored wires obtained using gas cleaning dust of aluminum production and used for surfacing of mining equipment is protected by Russian Federation patents [11, 12].

In this study, the structure and chemical composition of non-metallic inclusions of the surfaced metal obtained using a flux-cored wire of the Fe – C – Si – Mn – Cr – Ni – Mo – V system are determined. In the wire charge composition, instead of amorphous carbon, an additive, i.e. gas cleaning dust of aluminum production containing carbon and fluorine, is introduced. In addition, the effect of increasing the concentration of this additive on the level of contamination of the

¹ AvtoTransLogistik LLC, Novokuznetsk, Russia.

² EVRAZ United West Siberian Iron and Steel Works JSC, Novokuznetsk, Russia.

³ Siberian State Industrial University (SibGIU), Novokuznetsk, Russia (e-mail: kozyrev_na@mtsp.sbsiu.ru).

TABLE 1. Chemical Composition and Hardness of the Surfaced Layer

Sample	Elements content, wt.%									<i>HRC</i>
	C	Si	Mn	Cr	Mo	Ni	V	S	P	
1	0.33	0.78	0.91	1.37	0.46	0.46	0.58	0.069	0.022	45.0 – 50.7
2	0.47	0.86	1.02	1.52	0.51	0.52	0.64	0.066	0.023	46.8 – 51.4

surfaced metal with oxide non-metallic inclusions was determined.

The objective of this research is to study the microstructure and determine the composition of non-metallic inclusions in the surfaced layer obtained by the electric arc method using flux-cored wires of the Fe – C – Si – Mn – Cr – Ni – Mo – V system of the developed composition.

METHODS OF STUDY

The following powder-like materials were used as wire filler: silicon KR-1 according to GOST 2169–69, manganese MR-0 according to GOST 6008–82, chromium PkA-1M according to TU 14-1-1474–75, nickel PNK-1L5 according to GOST 9722–97, molybdenum PM-1 according to TU 48-19-102–82, electrolytic vanadium VEL-1 according to TU 48-4-335–86 and iron powder PZhV-1 according to GOST 9849–86. Instead of amorphous carbon, gas cleaning dust from aluminum production of the following chemical composition was introduced (a carbon-fluorine-containing additive), wt. %: 12.5 – 30.2 C_{tot}; 21 – 46 Al₂O₃; 18 – 27 F; 8 – 15 Na₂O; 0.4 – 6 K₂O; 0.7 – 2.3 CaO; 0.5 – 2.5 SiO₂; 2.1 – 3.3 Fe₂O₃; 0.07 – 0.9 MnO; 0.06 – 0.9 MgO; 0.09 – 0.19 S; 0.10 – 0.18 P.

Surfacing was carried out on plates made of St3 steel under AN-26S flux. Flux-cored wire with a diameter of 5 mm, made on a laboratory machine, was surfaced using an ASAW-1250 welding machine (tractor) in the following modes: $I = 420 - 520$ A, $U = 28 - 32$ V, welding rate $v_w = 7.2 - 9$ m/h. After surfacing, the samples were cooled at room temperature.

The properties of samples 1 and 2, which differed from each other by the content of a carbon-fluorine-containing additive introduced instead of amorphous carbon into the composition of the flux-cored wire, were investigated.

The chemical composition of the surfaced metal was determined by the x-ray fluorescence method on an XRF-1800 spectrometer and by the atomic emission method on a DFS-71 spectrometer. The hardness of the samples was measured by the Rockwell method in accordance with the requirements of GOST 9013–59.

Non-metallic inclusions were examined according to the standard procedure (GOST 1778–70) on unetched thin sections at $\times 100$ magnification using an OLYMPUS GX-51 metallographic microscope. In order to determine the chemical composition of non-metallic inclusions in the surfaced layer, as well as the elements distribution in the inclusions,

the samples were studied using a MIRA 3 LMH scanning electron microscope.

The microstructure of the surfaced metal was studied using an OLYMPUS GX-51 light microscope in a bright field in the magnification range of $\times 100 - \times 1000$ after etching the surface of the samples in a 4% nitric acid solution. The grain size was determined according to GOST 5639–82 at $\times 100$ magnification. The martensite dispersion was assessed by comparing the structure with the standards of the corresponding scales and sizes of martensite needles according to GOST 8233–56. The length of the martensite needles was assessed using the SiamsPhotolab700 software package for metallographic studies.

RESULTS AND DISCUSSION

The chemical composition of the surfaced layers of metal obtained using the produced test wire and the results of determining its hardness are given in Table 1.

When examining the surface of samples 1 and 2, a small amount of one-type globular silicate inclusions was revealed. The size of the inclusions does not exceed 24.5 μm . A quantitative analysis of the chemical composition of two identified inclusions was carried out according to two spectra in each.

TABLE 2. Chemical Composition of $\varnothing 14$ μm Non-Metallic Inclusion in Sample 1

Element	Elements content, wt. %	
	Spectrum 1 (bright phase)	Spectrum 2 (base)
O	4.42	35.81
F	47.43	12.98
Na	8.65	13.05
Mg	11.67	–
Al	3.97	20.03
Si	1.10	14.10
S	0.12	–
K	–	0.27
Ca	19.58	0.82
Ti	–	0.22
Mn	1.07	1.39
Fe	1.99	1.32
Total	100.00	100.00

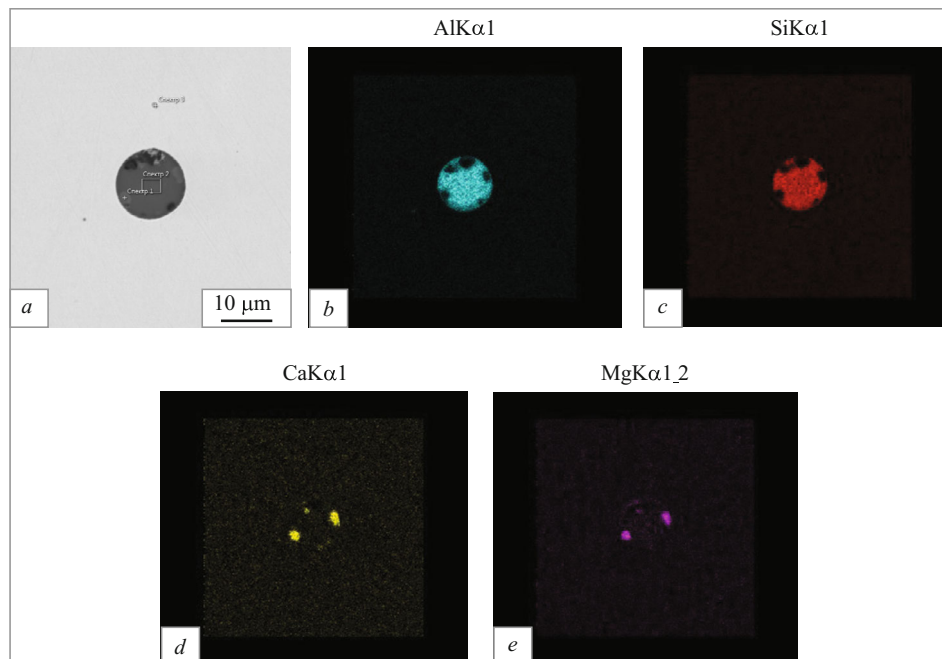


Fig. 1. Non-metallic inclusion of $\varnothing 14 \mu\text{m}$ in sample 1 (*a*, bright field) and distribution of alloying elements in it (dark field): *b*) Al; *c*) Si; *d*) Ca; *e*) Mg.

The results of the analysis of non-metallic inclusions identified in the samples are presented in Tables 2 – 6. The elements distribution on the selected area of all inclusions is shown in Figs. 1 – 4.

Analysis of the chemical composition of the $\varnothing 14 \mu\text{m}$ inclusion in sample 1 showed that the main components in it are Al, Si, Na, and F oxides. The bright phase in the inclusion consists of F, Ca, Mg, Na, and Al oxides (Fig. 1, Ta-

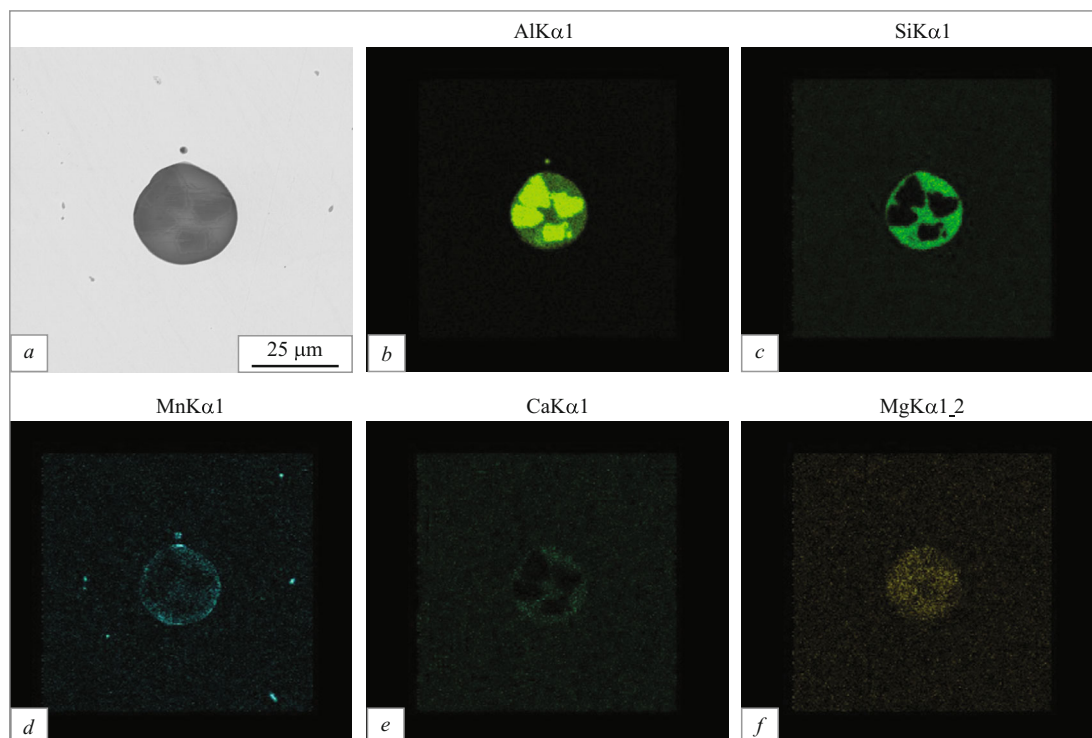


Fig. 2. Non-metallic inclusion of $\varnothing 24 \mu\text{m}$ in sample 1 (*a*, bright field) and the distribution of alloying elements in it (dark field): *b*) Al; *c*) Si; *d*) Mn; *e*) Ca; *f*) Mg.

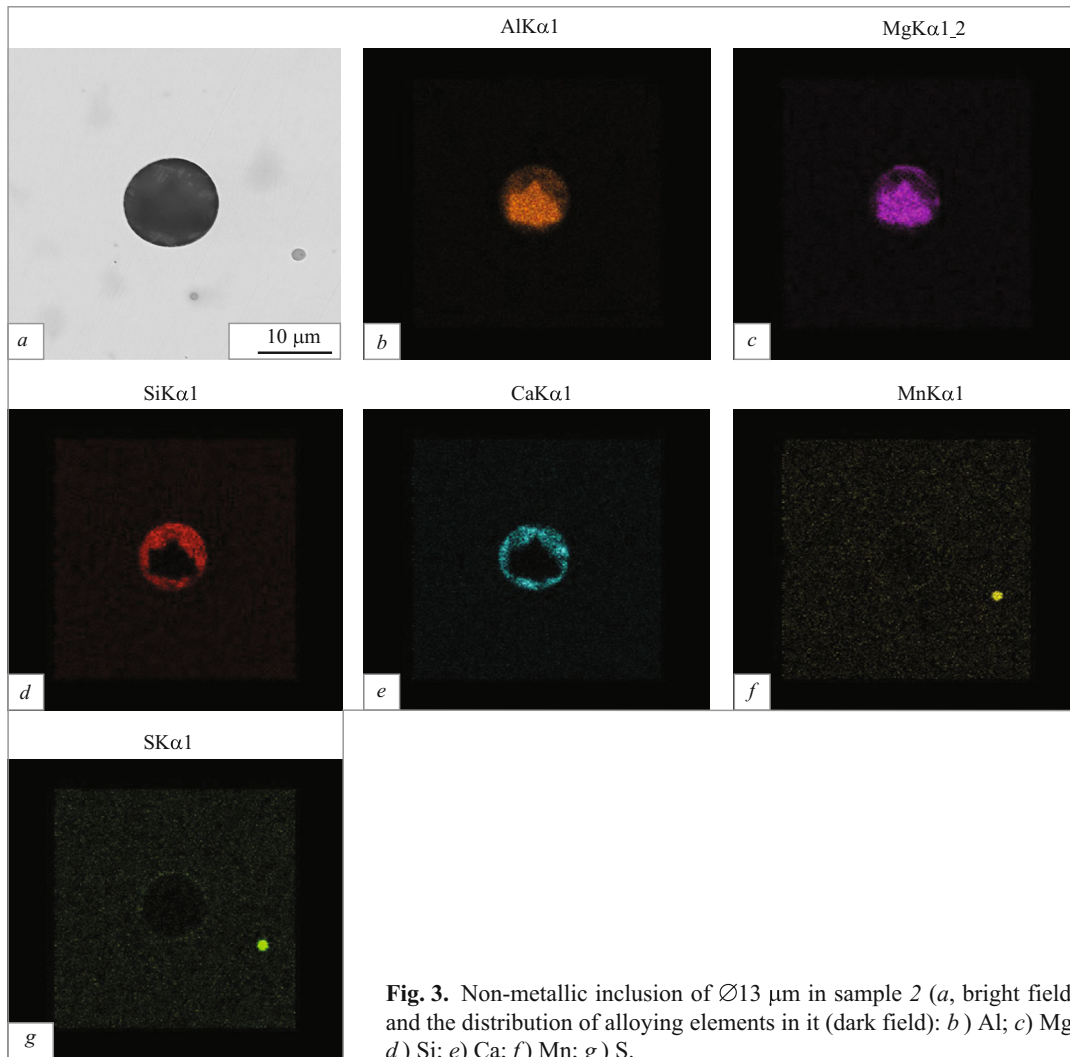


Fig. 3. Non-metallic inclusion of $\varnothing 13 \mu\text{m}$ in sample 2 (*a*, bright field) and the distribution of alloying elements in it (dark field): *b*) Al; *c*) Mg; *d*) Si; *e*) Ca; *f*) Mn; *g*) S.

ble 2). The $\varnothing 24 \mu\text{m}$ inclusion consists of Si, Al, F, Mn oxides; Ca and Mg are present in small amounts. The dark phase

in the inclusion consists of Al and Mn oxides with a low Mg content (Fig. 2, Table 3).

TABLE 3. Chemical Composition of $\varnothing 24 \mu\text{m}$ Non-Metallic Inclusion in Sample 1

Element	Elements content, wt.%	
	Spectrum 1 (bright phase)	Spectrum 2 (base)
O	36.46	46.74
F	12.53	–
Na	4.53	–
Mg	1.10	1.55
Al	16.32	47.01
Si	17.33	–
S	–	–
Ca	2.76	–
Mn	8.96	3.69
Fe	–	1.02
Total	100.00	100.00

TABLE 4. Chemical Composition of $\varnothing 13 \mu\text{m}$ Non-Metallic Inclusion in Sample 2

Element	Elements content, wt.%		
	Spectrum 1 (bright phase)	Spectrum 2 (base)	Spectrum 3
O	35.87	43.92	–
F	10.87	–	–
Mg	6.38	16.04	–
Al	13.39	37.35	–
Si	16.09	–	–
S	–	–	35.52
Ca	13.50	–	–
Mn	2.59	1.75	64.48
Fe	1.32	0.94	–
Total	100.00	100.00	100.00

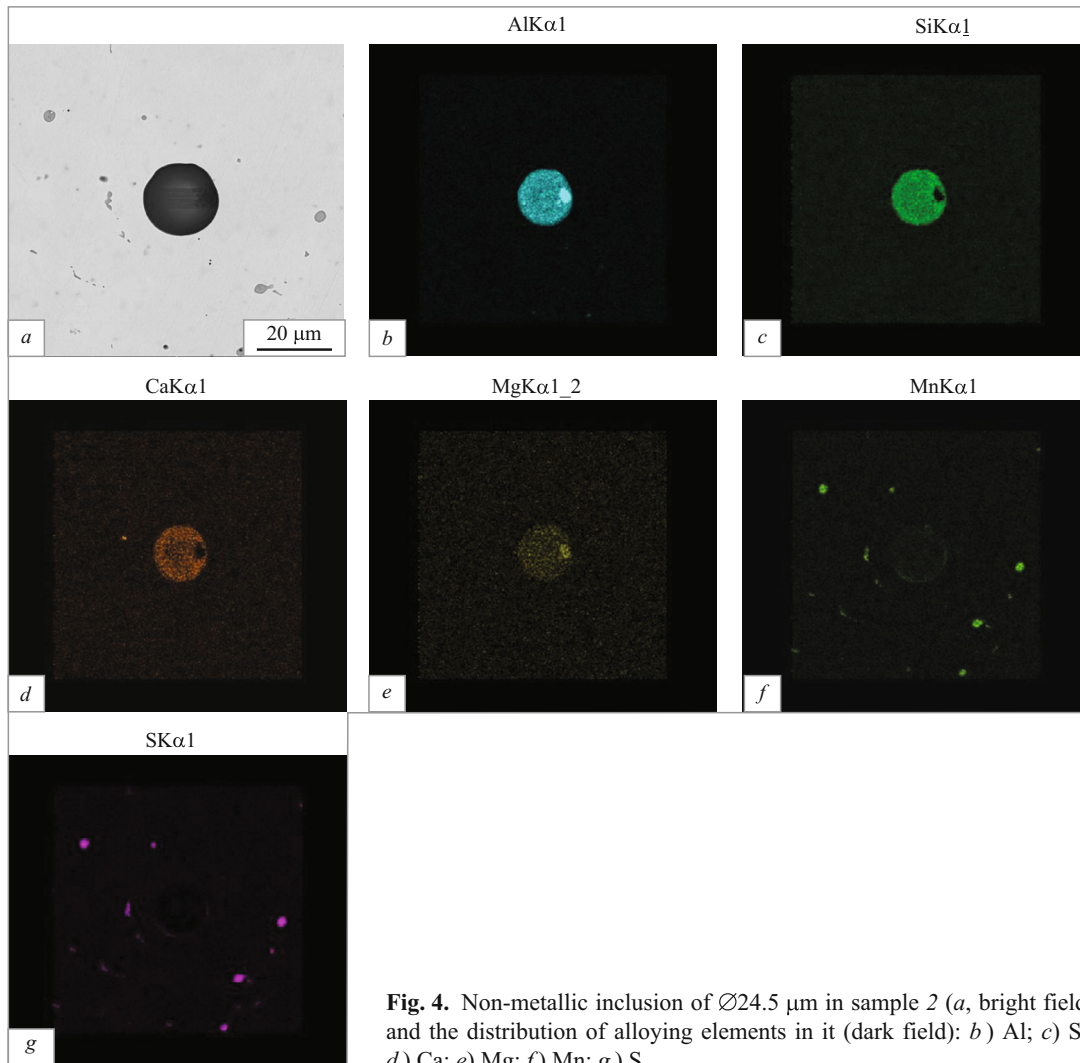


Fig. 4. Non-metallic inclusion of $\varnothing 24.5 \mu\text{m}$ in sample 2 (*a*, bright field) and the distribution of alloying elements in it (dark field): *b*) Al; *c*) Si; *d*) Ca; *e*) Mg; *f*) Mn; *g*) S.

Analysis of the chemical composition of the $\varnothing 13 \mu\text{m}$ inclusion in sample 2 showed that the main components in it are Al and Mg oxides with a low Mn content. The bright phase in the inclusion consists of Si, Ca, Al, F, Mg oxides and Mn traces (Fig. 3, Table 4). The $\varnothing 24.5 \mu\text{m}$ inclusion consists of Al, Si, Ca, F, Mn oxides, Na and Mg are present in small amounts. The dark component in the inclusion consists mainly of Al oxides, as well as a small content of Mg and Mn (Fig. 4, Table 5).

When examining the surfaced layer of samples 1 and 2, a significant amount of globular sulfide inclusions (the diameter of which is within $1 \mu\text{m}$) uniformly distributed in the plane of the thin section was also revealed. Typical manganese sulfides are shown in Figs. 2 and 3, and their composition is presented in Tables 3 and 4 (spectrum 3).

When studying the microstructure of the surfaced metal of samples 1 and 2 after etching, it was established that it has an identical dendritic (columnar) structure typical for cast metal and is martensite (Fig. 5).

The hardness of the surfaced metal, measured by the Rockwell method, was 45.0 – 50.7 HRC on sample 1 and 46.8 – 51.4 HRC on sample 2.

TABLE 5. Chemical Composition of $\varnothing 24.5 \mu\text{m}$ Non-Metallic Inclusion in Sample 2

Element	Elements content, wt.%		
	Spectrum 1 (base)	Spectrum 2 (dark phase)	Spectrum 3
O	47.07	44.89	–
Na	3.19	–	–
Mg	1.53	3.44	–
Al	23.46	47.18	–
Si	13.93	–	–
S	–	–	37.49
Ca	5.95	–	–
Mn	4.88	3.27	62.51
Fe	–	1.23	–
Total	100.00	100.00	100.00

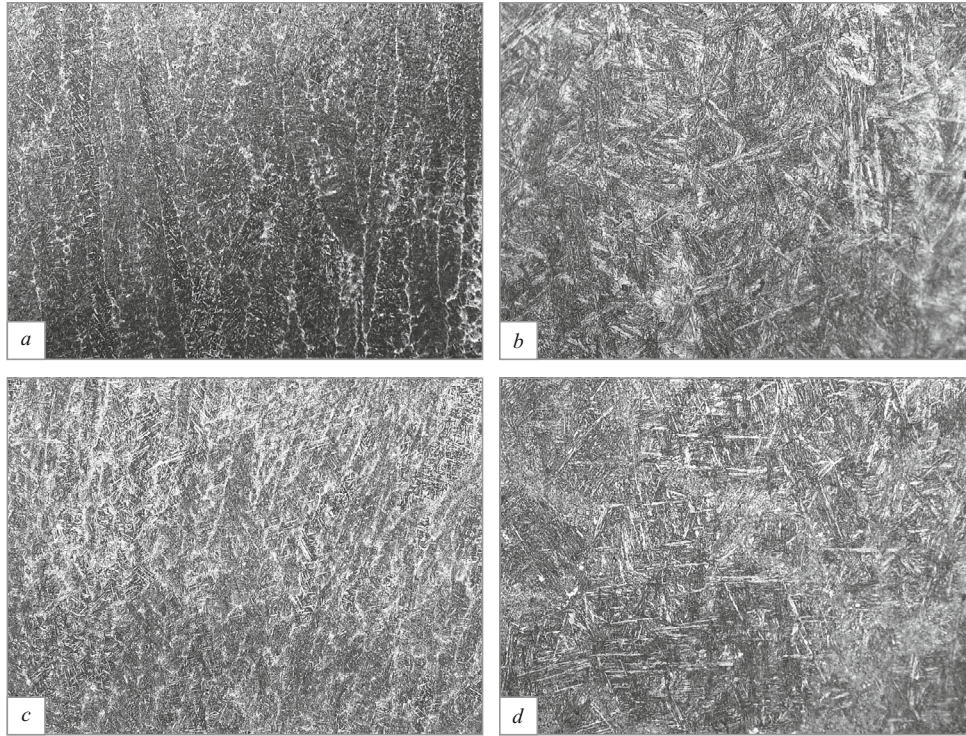


Fig. 5. Microstructure of the samples 1 (*a, b*) and 2 (*c, d*): *a, c* $\times 100$; *b, d* $\times 500$.

CONCLUSIONS

The chemical composition of non-metallic inclusions in metal surfaced from a flux-cored wire of the Fe – C – Si – Mn – Cr – Ni – Mo – V system with a carbon-fluorine-containing additive instead of amorphous carbon in its charge has been studied. It is shown that the inclusions mainly consist of Si, Al, F, Mn oxides; Ca and Mg are present in small amounts.

Metallographic analysis has shown that the microstructure of the surfaced layers consists of medium-acicular and coarse-acicular martensite formed within the boundaries of the former austenite grain, a small amount of residual auste-

nite in the form of separate sections and thin interlayers of δ -ferrite. The structure is uniform and dendritic.

An increase in the content of the carbon-fluorine-containing component of the flux-cored wire charge and, accordingly, an increase in the carbon content in the surfaced layer promotes an increase in the hardness of the surfaced metal.

According to the results of the studies performed, it has been established that with an increase in the carbon-fluorine-containing additive content in the composition of a flux-cored wire, an increase in the concentration of non-metallic inclusions containing F, Na and Al in the surfaced layer occurs. In its turn, it can adversely affect the physical and

TABLE 6. Chemical Composition of Particles in Surfaced Layer

Sample	D_p , * μm	Phase	Elements content, wt.%						
			Al	Si	Na	F	Ca	Mg	Mn
1	14.0	Base	24.0	14.0	13.0	13.0	–	–	–
		Bright phase	4.0	–	8.7	4.7	19.6	11.7	–
	24.0	Base	16.0	17.0	–	12.5	3.0	1.0	9.0
		Dark phase	47.0	–	–	–	–	1.5	3.7
2	13.0	Base	37.3	–	–	–	–	16.0	1.7
		Bright phase	13.4	16.0	–	11.0	13.5	6.4	2.6
	24.5	Base	23.5	14.0	3.0	–	6.0	1.5	5.0
		Dark phase	47.0	–	–	–	–	3.4	3.3

* Particle diameter.

mechanical properties of the surfaced layer. It is necessary to optimize the concentration of the carbon-fluorine-containing additive or use refining additives to reduce the contamination of the surfaced layer with non-metallic inclusions.

The research was performed within the framework of the state assignment (subject code 0809-2021-0013).

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