

## Performance of Surface Layers Applied by New Powder Wire in Highly Abrasive Wear

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**Abstract**—The influence of chromium (in high concentrations) as a reducing agent in the manufacture of Fe–C–Si–Mn–Cr–Ni–Mo powder wire is studied. Metal layers are applied to St3 steel plates under An-26S flux, with preliminary heating of the basic metal to 250–300°C. Powder wire (diameter 5 mm) manufactured on a laboratory machine is applied by means of an ASAW-1250 welding system, in the following conditions: current 420–520 A; voltage 28–32 V; welding rate 7.2–9.0 m/h. After surfacing, the metal is cooled to room temperature. In producing the powder wire, the filler consists of PZhV1 iron powder (State Standard GOST 9849–86); FS75 ferrosilicon powder (State Standard GOST 1415–93); FKh900A high-carbon ferrochrome powder (State Standard GOST 4757–91); FMn78(A) carbon ferromanganese (State Standard GOST 4755–91); PNK-1L5 nickel powder (State Standard GOST 9722–97); FMo60 ferromolybdenum powder (State Standard GOST 4759–91); FV50U0.6 ferrovanadium powder (State Standard GOST 27130–94); PK-1U cobalt powder (State Standard GOST 9721–79); and PVN tungsten powder (Technical Specifications TU 48-19-72–92). Within the chosen concentration ranges, carbon, manganese, chromium, molybdenum, nickel, and to some extent vanadium increase the hardness of the applied layer and also decrease the wear rate of the samples. The low viscosity of the matrix prevents the retention of tungsten carbide at the surface. Consequently, wear occurs not by uniform abrasion of the surface but by the extraction of high-strength carbon particles from the matrix. As a result, new cracks are formed in the matrix, which accelerates its wear. Multifactorial correlational analysis yields dependences of the hardness and wear resistance of the applied layer on the mass content of the elements in the Fe–C–Si–Mn–Cr–Ni–Mo powder wire. These dependences may be used to predict the hardness and wear resistance of the applied layer with change in its chemical composition.

**Keywords:** powder wire, surfacing, metal samples, wear resistance, microstructure, hardness, wear

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### INTRODUCTION

The primary approach to increasing the wear resistance of machine parts is to develop special powder wire for applying economically alloyed coatings [1–15].

The influence of the chromium and silicon concentration in the batch for Fe–C–Si–Mn–Cr–Ni–Mo powder wire with added vanadium on the microstructure, wear, and hardness of the applied metal was studied in [16–19]. Small quantities of nickel and tungsten were introduced in some samples.

In the present work, we study the influence of high concentrations of chromium in Fe–C–Si–Mn–Cr–Ni–Mo powder wire. In some samples, small quanti-

ties of nickel and tungsten are introduced: in the first batch (samples 1–4), chromium, nickel, and vanadium are introduced; in the second (samples 5–8), chromium, nickel, vanadium, and cobalt are introduced; in the third (samples 9–12), the main alloying element (chromium) is replaced by tungsten; and, in the fourth (samples 13–16), the molybdenum content is changed with constant nickel content.

Metal layers are applied to St3 steel plates under An-26S flux, with preliminary heating of the basic metal to 250–300°C. Powder wire (diameter 5 mm) manufactured on a laboratory machine is applied by means of an ASAW-1250 welding system, in the following conditions: current 420–520 A; voltage 28–32 V;

**Table 1.** Chemical composition of the applied metal

Sample	Content, wt %											
	C	Si	Mn	Cr	Ni	Mo	V	Co	W	Cu	S	P
1	0.24	0.19	0.93	1.83	0.14	0.69	0.60	0.002	0.020	0.07	0.036	0.017
2	0.25	0.27	0.96	1.65	0.33	0.68	0.60	0.003	0.080	0.09	0.033	0.010
3	0.29	0.28	0.93	1.67	0.54	0.57	0.58	0.002	0.020	0.06	0.029	0.014
4	0.25	0.15	0.92	1.65	0.65	0.60	0.59	0.002	0.050	0.06	0.034	0.012
5	0.23	0.12	0.85	1.45	0.53	0.51	0.68	0.080	0.001	0.05	0.033	0.017
6	0.21	0.23	0.89	1.45	0.54	0.55	0.54	0.030	0.001	0.07	0.031	0.015
7	0.17	0.18	0.85	1.40	0.52	0.54	0.63	0.050	0.001	0.06	0.029	0.016
8	0.17	0.28	0.91	1.32	0.45	0.46	0.59	0.060	0.001	0.06	0.032	0.015
9	0.17	0.19	0.80	0.09	0.56	0.25	0.56	0.006	2.250	0.12	0.047	0.016
10	0.12	0.20	0.79	0.07	0.53	0.08	0.51	0.001	2.170	0.09	0.053	0.025
11	0.14	0.18	0.65	0.06	0.49	0.64	0.45	0.002	1.970	0.09	0.033	0.020
12	0.12	0.22	0.70	0.07	0.50	0.54	0.47	0.001	2.110	0.10	0.054	0.027
13	0.22	0.18	0.64	1.59	0.46	0.08	0.48	0.001	0.003	0.09	0.031	0.017
14	0.14	0.23	0.73	1.73	0.53	0.23	0.55	0.001	0.001	0.09	0.033	0.017
15	0.16	0.20	0.84	1.70	0.58	0.52	0.63	0.001	0.001	0.08	0.035	0.016
16	0.24	0.19	0.93	1.83	0.14	0.69	0.60	0.002	0.020	0.07	0.036	0.017

welding rate 7.2–9.0 m/h. After surfacing, the metal is cooled to room temperature.

In producing the powder wire, the filler consists of PZhV1 iron powder (State Standard GOST 9849–86); FS75 ferrosilicon powder (State Standard GOST 1415–93); FKKh900A high-carbon ferrochrome powder (State Standard GOST 4757–91); FMn78(A) carbon ferromanganese (State Standard GOST 4755–91); PNK-1L5 nickel powder (State Standard GOST 9722–97); FMo60 ferromolybdenum powder (State Standard GOST 4759–91); GV50U0.6 ferrovanadium powder (State Standard GOST 27130–94); PK-1U cobalt powder (State Standard GOST 9721–79); and PVN tungsten powder (Technical Specifications TU 48-19-72–92).

The chemical composition of the applied metal is determined by an X-ray fluorescent method on an XRF-1800 spectrometer and by the atomic-emission method on a DFS-71 spectrometer (Table 1).

The hardness is measured by the Rockwell method in accordance with State Standard GOST 9013–59). Metallographic data for microsections are obtained by means of an Olympus GX-51 optical microscope in a light field (magnification 100–1000 $\times$ ), after etching the sample surface in 4% nitric acid solution. The grain size is determined in accordance with State Standard GOST 5639–82 (magnification 100 $\times$ ). The dispersity of the martensite is determined by comparing the structure with standards corresponding in scale and size of the martensite needles (in accordance with State Standard GOST 8233–56, Table 6). The length of the martensite needles is determined by means of

Siams Photolab 700 metallographic software. The presence of nonmetallic inclusions in longitudinal samples of the applied layer is investigated in accordance with State Standard GOST 1778–70. The polished surface is studied by means of a LaboMet-II metallographic microscope (magnification 100 $\times$ ).

The wear of the applied layer on the experimental samples is determined in tests on a 2070 SMT-1 machine, in a disk–shoe configuration, with the following parameters: shaft speed with respect to the sample 100 rpm; frictional torque 3 N m; and force of the disk on the sample 600 N.

## DISCUSSION OF THE RESULTS

Metallographic data show that the microstructure of the layer applied by means of Fe–C–Si–Mn–Cr–Ni–Mo powder wire, with microquantities of vanadium and cobalt, consists of martensite formed within the boundaries of the former austenite grains; residual austenite present in small quantities as individual particles; and thin layers of  $\delta$  ferrite along the boundaries of the former austenite grains. In the absence of chromium, we observe ferrite–pearlite structure. Analysis of the results shows different influence of different chemical elements on the hardness of the applied layer and the wear rate. Within the given concentration ranges, additions of carbon, chromium, molybdenum, nickel, manganese, and to a small extent vanadium increase the hardness of the applied layer and also decrease the wear rate of the samples (Table 2, Figs. 2a–2f).

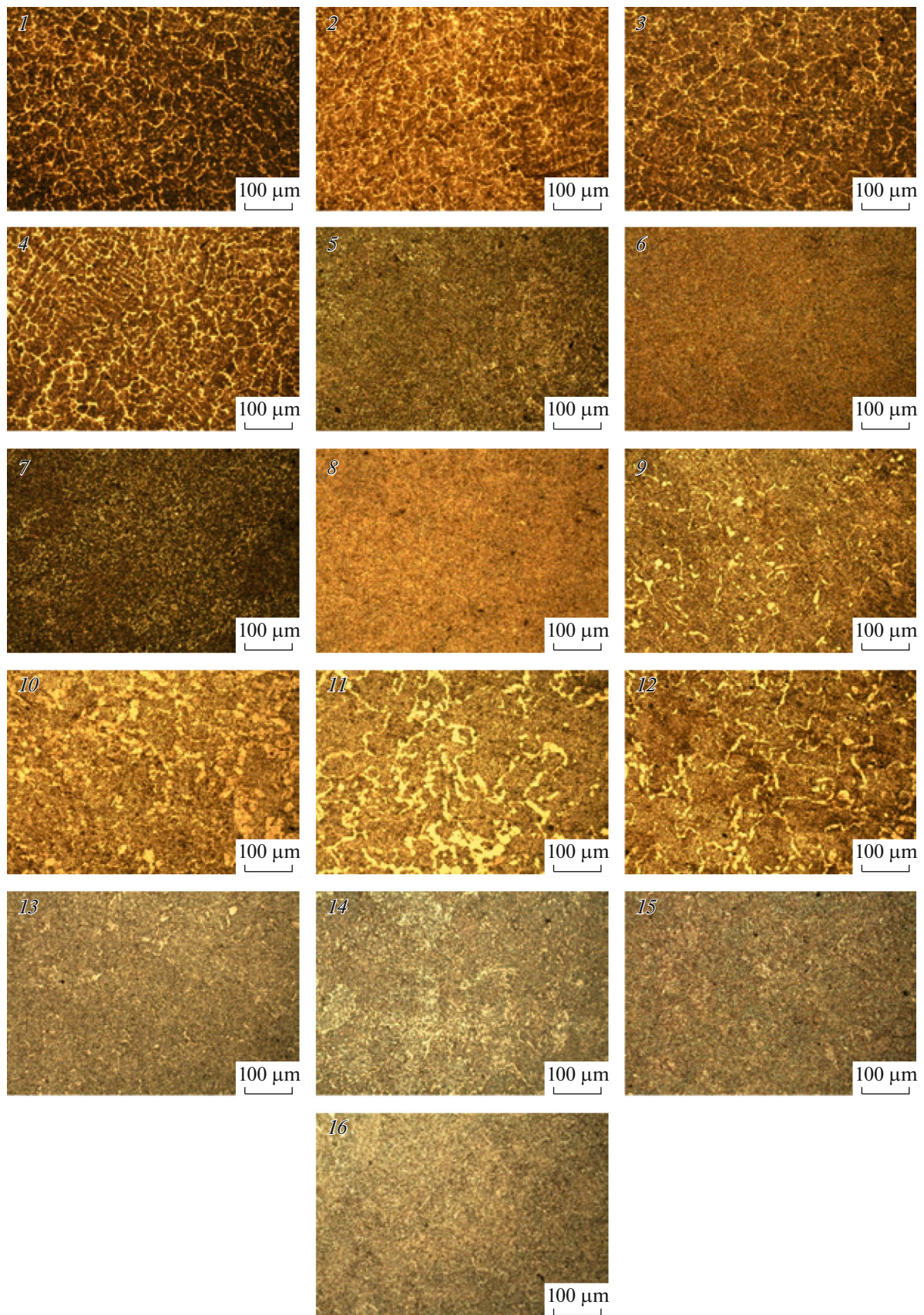


Fig. 1. Microstructure of applied layer for samples 1–16.

**Table 2.** Structure and size of the martensite needles and hardness and abrasion rate of the applied layers

Sample	Structure	Needle size, $\mu\text{m}$	Austenite grain-size score	HRC	Abrasion rate, g/turn
1	Martensite	3–10	6, 5	41	$2.90 \times 10^{-5}$
2	Martensite	3–8	6, 5	40	$3.70 \times 10^{-5}$
3	Martensite	4–8	5, 6	40	$3.58 \times 10^{-5}$
4	Martensite	2–8	5, 6	41	$3.59 \times 10^{-5}$
5	Martensite	3–5	6, 5	25	$13.60 \times 10^{-5}$
6	Martensite	3–5	6	21	$16.50 \times 10^{-5}$
7	Martensite	3–5	5, 6	21	$11.50 \times 10^{-5}$
8	Martensite	2–5	5, 6	21	$8.88 \times 10^{-5}$
9	Ferrite–pearlite	–	4, 5	17	$11.50 \times 10^{-5}$
10	Ferrite–pearlite	–	4, 5	16	$3.96 \times 10^{-5}$
11	Ferrite–pearlite	–	4	16	$17.00 \times 10^{-5}$
12	Ferrite–pearlite	–	4	16	$18.60 \times 10^{-5}$
13	Martensite	2–5	6, 5	20	$15.00 \times 10^{-5}$
14	Martensite	2–4	6	25	$13.40 \times 10^{-5}$
15	Martensite	2–5	6	29	$15.00 \times 10^{-5}$
16	Martensite	2–4	6	28	$9.20 \times 10^{-5}$

**Table 3.** Content of nonmetallic inclusions

Sample	Silicates	Point oxides
1	1b, 2b, 3a	1a
2	2b, 2a, 3a	1a
3	2b, 3a	1a
4	2b, 3a	1a
5	2b, 2a, 3a	1a
6	1b, 2b, 3a	1a
7	2b, 3a	1a
8	2b, 3a (1b)	1a
9	1b, 2b, 3a	1a
10	1b, 2b, 2a	1a, 2a
11	1b, 2b, 3a	1a
12	1b, 2b, 3a	1a
13	1b, 2b	1a, 2a
14	2b, 1b	1a
15	1b, 2b	1a
16	2b, 1b	1a, 2a

The introduction of cobalt (Fig. 2g) has a complex effect: both the hardness and the wear increase. With increase in tungsten content (Fig. 2h), the hardness declines, and the wear rate rises. This may be explained in terms of the structure of the material or the matrix. In the absence of solid carbide particles in the matrix, the introduction of cobalt has a negative effect. The influence of tungsten on the hardness of the applied layer and the wear rate depends primarily on the structure of the metal matrix. Replacement of martensitic structure in the applied layer by ferrite–pearlite structure leads to no great increase in the wear resistance. Wear and hardness tests for this structure indicate that, in terms of abrasive wear, tungsten is inferior to chromium as the primary alloying element. When using tungsten, the low viscosity of the matrix prevents the retention of tungsten carbide at the surface. Consequently, wear does not occur by uniform abrasion of the surface but by the extraction of high-strength carbon particles from the matrix. As a result, new cracks are formed in the matrix, which accelerates its wear.

The content of nonmetallic inclusions has little influence on the sample wear (Table 3).

The general pattern of influence of each element in the applied layer on its hardness and wear rate has

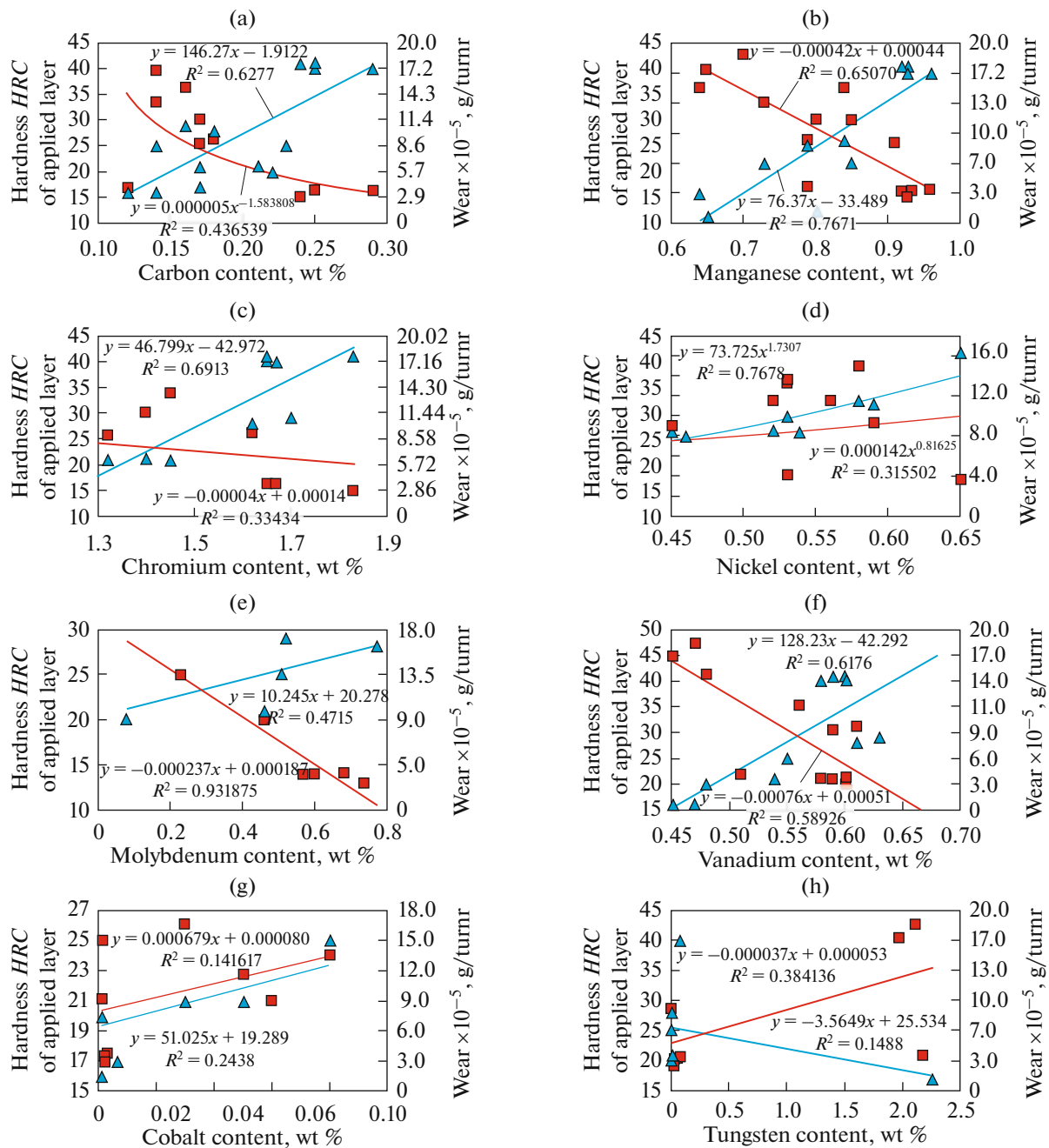


Fig. 2. Dependence of the hardness (■) and wear (▲) of the applied metal layer on the content of carbon (a), manganese (b), chromium (c), nickel (d), molybdenum (e), vanadium (f), cobalt (g), and tungsten (h).

been considered, but their combined influence remains to be established. To that end, we may use statistical methods to identify how various factors affect the outcome [20].

In the analysis, we determine the factors that affect a particular characteristic and select the most significant of these (Tables 1 and 2). Then we check the reliability and uniformity of the initial data and their fit to a normal distribution. On that basis, we may construct a mathematical model of the multifactorial system.

Since the systems considered include independent factors, we use determinate factorial analysis.

Analysis of the results permits the formulation of the corresponding formulas. Their adequacy may be verified in terms of the mean error of the approximation

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

where  $m$  is the number of observations;  $\tilde{Y}_i$  is the calculated result; and  $Y_i$  is the actual result.

By this means, we may derive dependences of the hardness and wear resistance of the applied layer on the mass content of the elements in the Fe–C–Si–Mn–Cr–Mo–Ni–V–Co powder wire.

The expression for the hardness of the applied layer takes the form

$$\begin{aligned} HRC = & 4.82 + 45.39C + 30.14Si - 29.47Mn \\ & + 17.89Cr - 8.00Ni + 12.095Mo + 46.45V \\ & - 164.74Co + 11.96W - 306.3Cu \\ & + 505.72S - 996.48P. \end{aligned}$$

The error of this approximation is 0.34%.

The expression for the wear rate of the applied layer takes the form

$$\begin{aligned} W = & 0.000237 - 0.00035C + 0.0000556Si \\ & - 0.00038Mn + 0.000245Cr + 0.000168Ni \\ & + 0.000141Mo - 0.00072V + 0.00281Co \\ & + 0.000141W + 0.00101Cu + 0.00166S - 0.00351P. \end{aligned}$$

The error of this approximation is 3.21%.

The calculated mean errors of the approximation indicate that these formulas may be used in practice.

## CONCLUSIONS

Within the chosen concentration ranges, carbon, manganese, chromium, molybdenum, nickel, and to some extent vanadium increase the hardness of the applied layer and also decrease the wear rate of the samples.

The low viscosity of the matrix prevents the retention of tungsten carbide at the surface. Consequently, wear occurs by uniform abrasion of the surface but by the extraction of high-strength carbon particles from the matrix. As a result, new cracks are formed in the matrix, which accelerates its wear.

Multifactorial correlational analysis yields dependences of the hardness and wear resistance of the applied layer on the mass content of the elements in the Fe–C–Si–Mn–Cr–Mo–Ni–V–Co powder wire. These dependences may be used to predict the hardness and wear resistance of the applied layer with change in its chemical composition.

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