Metallurgical technologies / Металлургические технологии

UDC 621.762.04:624.567.1:669
DOI 10.17073/0368-0797-2023-4-403-409

Original article
Оригинальная статья

Development of flux-cored wire of Fe – C – Si – Mn – Cr – W – V system with additives of carbon-fluorine-containing material and titanium

A. A. Usol'tsev[1], **N. A. Kozyrev**[2], **L. P. Bashchenko**[1], **R. E. Kryukov**[1], **A. V. Zhukov**[1]

[1] **Siberian State Industrial University** (42 Kirova Str., Novokuznetsk, Kemerovo Region – Kuzbass 654007, Russian Federation)
[2] **I.P. Bardin Central Research Institute of Ferrous Metallurgy** (23/9 Radio Str., Moscow 105005, Russian Federation)

n.kozyrev@chermet.net

Abstract. The paper considers research of quality of the electric arc coating obtained using flux-cored wire of the Fe–C–Si–Mn–Cr–W–V system with additives of carbon-fluorine-containing material and titanium. The formation of an electric arc coating was carried out using an automatic arc welding machine ASAW-1250 with a new chromium-containing flux-cored wire on plates made of St3 steel. To exclude mixing of the deposited metal with the substrate steel, multilayer surfacing was conducted. The surfacing mode was calculated and refined experimentally. The authors studied the composition and properties of the surface of the electric arc coating after surfacing. As a substitute for amorphous carbon they used a carbon-fluorine-containing material (dust of gas purification of aluminum production). Surfacing was carried out under a flux made from slag produced by silicomanganese with a high content of sulfur. A regression analysis of influence of the deposited layer's chemical composition on its hardness and wear rate was carried out and mathematical models of the investigated performance characteristics of the electric arc coating were obtained. With an increase in the content of chromium, tungsten, carbon and silicon, hardness of the deposited metal and its resistance to abrasive wear increase. The results of the conducted research make it possible to develop measures ensuring the required level of performance characteristics of the electric arc coating and can be used to make a forecast of hardness of the deposited layer and its wear resistance when the chemical composition of the metal changes, to predict the operational resistance of rolling rolls deposited with wires of the PP-Np-35V9Kh3SF type. Mathematical models of hardness of the deposited layer and its wear resistance help to clarify the mechanism of hardening and formation of protective properties of the surface layers of rolling rolls by means of electric arc coatings deposited with flux-cored wires.

Keywords: flux-cored wire, electric arc coating, multilayer surfacing, rolling rolls, hardness, wear rate

For citation: Usol'tsev A.A., Kozyrev N.A., Bashchenko L.P., Kryukov R.E., Zhukov A.V. Development of flux-cored wire of Fe – C – Si – Mn – Cr – W – V system with additives of carbon-fluorine-containing material and titanium. *Izvestiya. Ferrous Metallurgy*. 2023;66(4):403–409. https://doi.org/10.17073/0368-0797-2023-4-403-409

Разработка порошковой проволоки системы Fe – C – Si – Mn – Cr – W – V с присадками углеродфторсодержащего материала и титана

А. А. Усольцев[1], **Н. А. Козырев**[2], **Л. П. Бащенко**[1], **Р. Е. Крюков**[1], **А. В. Жуков**[1]

[1] **Сибирский государственный индустриальный университет** (Россия, 654007, Кемеровская обл. – Кузбасс, Новокузнецк, ул. Кирова, 42)
[2] **Центральный научно-исследовательский институт черной металлургии им. И.П. Бардина** (Россия, 105005, Москва, ул. Радио, 23/9)

n.kozyrev@chermet.net

Аннотация. В работе исследуется качество электродугового покрытия, полученного с использованием порошковой проволоки системы Fe–C–Si–Mn–Cr–W–V с присадками углеродфторсодержащего материала и титана. Формирование электродугового покрытия осуществляется с помощью аппарата для автоматической дуговой сварки ASAW-1250 с применением новой хромсодержащей порошковой проволоки на пластины из стали марки Ст3. Для исключения перемешивания наплавляемого металла со сталью подложки проводят многослойную наплавку. Режим наплавки рассчитывается и уточняется экспериментальным путем. Авторы исследовали состав и свойства поверхности электродугового покрытия после наплавки. В качестве заменителя аморфного углерода используется углеродфторсодержащий материал (пыль газоочистки алюминиевого производства). Наплавку осуществляли под флюсом, изготовленным из шлака производства силикомарганца с повышенным содержанием серы. Проведенный регрессионный анализ показывает влияние химического состава наплавленного слоя на его твердость и скорость износа. В работе получены математические модели исследуемых эксплуатационных характеристик электродугового покрытия. При увеличении содержания хрома, вольфрама, углерода и кремния повышаются твердость наплавленного металла и устойчивость его к абразивному износу. Результаты проведенных исследований позволяют выработать мероприятия для обеспечения требуемого уровня эксплуатационных характеристик электродугового покрытия и могут использоваться для составления прогноза твердости наплавленного слоя и его износостойкости при изменении химического состава металла, прогнозировать эксплуатационную стойкость прокатных валков, наплавленных проволоками типа ПП-Нп-35В9Х3СФ. Математические модели твердости наплавленного слоя и его износостойкости позволяют уточнить механизм упрочнения и формирования защитных свойств поверхностных слоев прокатных валков посредством электродуговых покрытий, наплавленных порошковыми проволоками.

Ключевые слова: порошковая проволока, электродуговое покрытие, многослойная наплавка, прокатные валки, твердость, скорость износа

Для цитирования: Усольцев А.А., Козырев Н.А., Бащенко Л.П., Крюков Р.Е., Жуков А.В. Разработка порошковой проволоки системы Fe – C – Si – Mn – Cr – W – V с присадками углеродфторсодержащего материала и титана. *Известия вузов. Черная металлургия*. 2023;66(4):403–409. https://doi.org/10.17073/0368-0797-2023-4-403-409

Introduction

Rolling rolls constitute the primary technological tool in the steel mill rolling process. During their operation, amidst the plastic deformation of the metal, these rolls endure significant specific pressures and thermal effects, leading to intensive wear [1 – 3]. In light of this, the issue of roller repair quality has become more critical. Recently, there has been a notable increase in the widespread application of restorative arc surfacing to repair rolling mill rolls, using powder wires [2; 4; 5]. However, the use of flux-cored wires for surface welding comes with various drawbacks. In order to ensure the execution of high-quality repair procedures, there arises an essential need to enhance the composition of the wire charge and refine its application technique [6 – 8]. Consequently, the theoretical and experimental exploration of the physical characteristics, processes, and mechanisms involved in reinforcing and developing protective properties within the surface layers of rolls through electric arc coatings, deposited using flux-cored wires, remains relevant and holds scientific and practical significance.

It is worth mentioning that the utilization of presently employed flux-cored wires for the surfacing of rolling rolls is linked to a series of defects that emerge during the surfacing process. These include the high cost and scarcity of surfacing materials, along with the imperfect nature of surfacing technologies [9 – 11]. Identifying and rectifying the flawed structure of these coatings, which contributes to their premature deterioration, holds significant importance [12 – 14]. The advancement of technological surfacing materials [15 – 17], capable of yielding low-carbon martensite structures in the deposited metal, is a subject of interest.

Flux-cored wires within the Fe–C–Si–Mn–Cr–W–V system find extensive application in the surfacing of rolling rolls [18 – 20]. Simultaneously, for the restoration of rolls that operate under the most demanding conditions, the flux-cored wires of the PP-Np-35V9Kh3SF grade in accordance with the State Standard GOST 26101–84 are predominantly employed [19 – 21]. By modifying the composition of the charge within these flux-cored wires and incorporating several elements into their makeup, it becomes feasible to enhance the wear resistance of the deposited layer and extend the operational lifespan of the deposited rolls. Enhancing and altering the chemical composition of the flux-cored wires employed in surfacing presents a multifaceted scientific and manufacturing challenge, requiring a solution that meets the criteria of both economic viability and environmental sustainability [21 – 23].

The objective of this study is to establish patterns governing the augmentation of wear resistance and hardness in electric arc coatings applied to rolling rolls via the use of flux-cored wires within the Fe–C–Si–Mn–Cr–W–V system. This enhancement is achieved through the introduction of titanium and carbon-fluorine-containing material into their composition.

Materials and methods

The processes involved in surfacing and the fabrication of flux-cored wire, as well as the formulation of the filler for the flux-cored wire under investigation and the welding flux, are elaborated upon in references [20 – 22].

In the pursuit of developing a new flux-cored wire, a comparative benchmark was established using wire PP-Np-35V9Kh3SF, produced with graphite grade GL-1 (sample *1*). Subsequently, adjustments were made to the concentrations of titanium (samples *2 – 4*) and the carbon-fluorine-containing material (samples *5 – 9*) for comparison.

Before commencing the production of flux-cored wires, the quantities of powder materials were preliminarily calculated. These materials were meticulously weighed using laboratory analytical scales AUX 120. The blending of the powders was conducted on laboratory rotary mixers for a minimum of 30 min. The manufacturing of the flux-cored wire was executed using a laboratory machine: the strip was drawn through a die, resulting in the formation of the flux-cored wire, which was then wound onto a drum.

The surfacing of electric arc coatings was conducted using an ASAW-1250 welding tractor, employing a custom-made flux-cored wire on steel plates in five distinct layers. This stratification aimed to prevent the mingling of the deposited metal with the underlying substrate steel. The surfacing parameters were calculated and fine-tuned through experimental adjustments. Post-surfacing, an analysis of the composition and properties of the resulting electric arc coatings were undertaken.

The chemical composition of the deposited coatings was determined using *X*-ray fluorescence via an XRF-1800 spectrometer and atomic emission analysis with a DFS-71 spectrometer. For several samples, the metal's chemical composition was ascertained using chemical techniques: carbon content was measured in accordance with State Standard GOST 12344–2003, sulfur levels were determined following State Standard GOST 12345–2001, and phosphorus content was evaluated adhering to State Standard GOST 12347–77.

Samples designated for macro- and microstructure examination, hardness testing, and wear resistance analysis were prepared using a methodology encompassing cutting via a KKS 315L cutting machine, subsequent grinding on a 3D725 surface grinder, and final polishing utilizing a FROMMIA 835 SE polishing machine.

The configuration of sample cutting is depicted in Fig. 1.

In order to assess the mechanical properties, macrosections measuring 20×55×14 mm were derived from the cut samples. Hardness measurements were conducted using the Rockwell method on a TK-14-250 hardness tester, following the specifications outlined in State Standard GOST 9013–59. This involved indenting a conical diamond tip with an apex angle of 120°.

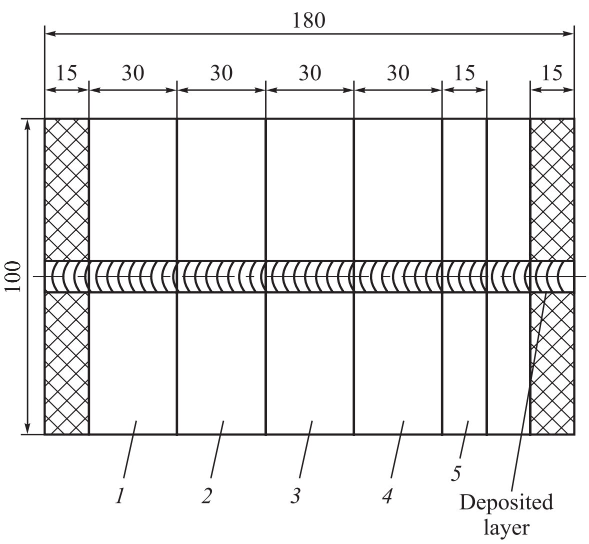

Fig. 1. Scheme of samples cutting for testing:
1 and *2* – for obtaining macro- and micro-plates;
3 and *4* – for tests on hardness and wear resistance;
5 – for hydrogen content determination

Рис. 1. Схема вырезки образцов
для проведения испытаний и анализа:
1 и *2* – для изготовления макро- и микрошлифов;
3 и *4* – для испытаний на твердость и износостойкость;
5 – для определения содержания водорода

Wear tests are presently conducted in accordance with State Standard GOST 23.208–79. This standard pertains to both metallic materials and metallic coatings, stipulating the method for evaluating their resistance to abrasive wear during friction against loosely bound abrasive particles. The core of this method involves rubbing test and reference material samples against abrasive particles introduced into the friction zone and pressed onto the sample by a rotating rubber roller. The wear of these test and reference material samples is measured, with the wear resistance of the test material estimated through a comparison of the wear on the reference and test samples. The outcomes are processed based on the recorded weight of the samples prior to and post the tests, determining the arithmetic mean values of weight loss for both the reference sample and the samples under study.

In order to analyze the influence of the chemical composition of flux-cored wires on the wear rate (degree) and hardness of electric arc coatings, we employed multifactorial correlation analysis. This approach enables us to scrutinize the patterns of changes in specific indicators as a function of various factors. Initially, we identified the factors affecting the indicator in question, selecting the most significant among them. Subsequently, we examined the initial data for reliability, uniformity, and adherence to the normal distribution law. This allowed us to formulate a model of the factor system, using deterministic factor analysis given the presence of independent factor characteristics in the systems being studied.

The rate of abrasion of the deposited layer of the test samples was determined through wear tests performed on a 2070 SMT-1 machine. The fundamental kinematic diagram of this machine is presented in Fig. 2. The lower sample's shaft rotation frequency measurement range (range *A*) was 75 – 750 min^{-1}, while the friction torque measurement range (range *I*) spanned 1 – 10 N·m. The friction machine 2070 SMT-1 can function with both closed and open power circuits, and operates as follows: power is transmitted from the electric motor *2* to both the lower *5* and upper *6* samples via a belt drive *10*. Sample *6* is mounted on the shaft of the folding carriage *7*, which is counterbalanced by the spring mechanism *8*. An elastic torsion sensor *9* for friction torque, along with a non-contact current collector, is installed on the drive shaft of the lower sample, with its signal relayed control panel.

The samples are subjected to loading through a spring bar mechanism *4*. The applied normal force is adjusted by manipulating the loading unit's handle, with the measurements conveyed to the control panel via a flexible link connected to a resistor situated within this unit.

The rotation speed is measured utilizing a rate generator *3*, positioned on the engine shaft, while the rotations of the lower sample *5* are counted by means of a non-contact sensor *1*. The shaft-bushing employed for sample wear, which is crafted from P18 steel, is incorporated.

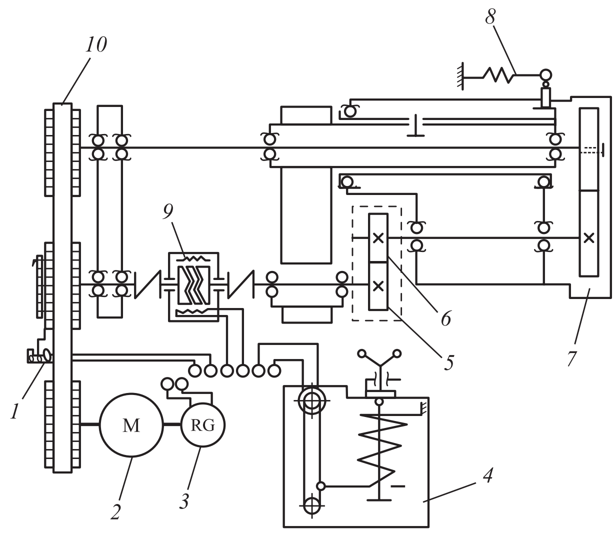

Fig. 2. Basic kinematic scheme of the 2070 СМТ-1 machine:
1 – contactless speed sensor; *2* – electric motor; *3* – rate generator;
4 – loading unit (spring mechanism);
5 and *6* – lower and upper samples; *7* – carriage;
8 – spring mechanism; *9* – friction torque sensor;
10 – flat-toothed belt drive

Рис. 2. Принципиальная кинематическая схема машины 2070 СМТ-1:
1 – бесконтактный датчик количества оборотов;
2 – электродвигатель; *3* – тахогенератор;
4 – узел нагружения (пружинный механизм);
5 и *6* – нижний и верхний образцы; *7* – каретка;
8 – пружинный механизм; *9* – датчик момента трения;
10 – плоскозубая ременная передача

Results and discussion

The chemical composition of the deposited layer obtained using the experimental powder wire is outlined in Table 1, and the wear rates of the samples are summarized in Table 2.

Variations in hardness and wear rate concerning the content of different elements are visualized in Fig. 3.

The utilization of mathematical and statistical methods has facilitated the development of a mathematical model depicting the influence of the chemical composition of the deposited layer on its hardness and wear rate.

The validity of the acquired relationships was assessed through the mean approximation error, calculated as follows

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

where m represents the number of observations; $\tilde{Y}_i$ stands for the calculated resultant indicator; $\tilde{Y}_i$ corresponds to the actual value of resultant indicator.

Regression analysis of the influence of the chemical composition of the deposited layer on its hardness and wear rate is expressed by the following equations:

– HRC hardness:

$$-39.056 + 58.725\text{C} + 4.983\text{Si} + 37.87\text{Mn} +$$
$$+ 6.058\text{Cr} - 7.096\text{Cu} - 107.503\text{Mo} - 0.341\text{V} - 0.435\text{W}$$

(approximation error is 0.0012 %);

– wear rate, g/rot:

$$-0.0000741 + 0.00042\text{C} - 0.00043\text{Si} +$$
$$+ 0.000258\text{Mn} - 0.00022\text{Cr} + 0.000398\text{Cu} +$$
$$+ 0.00419\text{Mo} - 0.00019\text{V} + 0.0000372\text{W}$$

(approximation error is 0.0011 %).

The hardness and resistance to abrasive wear of the deposited metal exhibit an increase with an escala-

Table 1

Chemical composition of the deposited layers

Таблица 1. **Химический состав наплавленных слоев**

Sample	Content of elements, wt. %														HRC
	C	Si	Mn	Cr	Cu	Mo	V	W	Ni	P	S	Al	Co	Nb	Ti	
1	0.39	1.26	1.69	3.43	0.14	0.11	0.21	8.76	0.12	0.037	0.022	0.060	0.04	0.010	0.020	58.2
2	0.37	1.31	1.74	3.25	0.13	0.11	0.20	8.19	0.12	0.034	0.021	0.110	0.04	0.010	0.030	58.4
3	0.39	1.23	1.76	3.35	0.17	0.10	0.20	8.38	0.10	0.032	0.022	0.100	0.03	0.020	0.030	54.5
4	0.35	1.18	1.73	3.03	0.18	0.09	0.19	7.42	0.13	0.031	0.021	0.090	0.04	0.020	0.030	57.0
5	0.17	0.92	1.76	1.43	0.06	0.05	0.06	3.68	0.07	0.018	0.029	0.020	0.02	0.010	0.006	43.4
6	0.18	0.83	1.55	0.84	0.06	0.03	0.04	2.23	0.06	0.014	0.033	0.009	0.01	0.010	0.007	34.8
7	0.15	0.96	1.66	1.12	0.07	0.03	0.06	3.31	0.07	0.017	0.036	0.008	0.01	0.006	0.007	39.0
8	0.09	0.76	1.46	0.60	0.06	0.02	0.03	1.50	0.06	0.013	0.033	0.004	0.01	0.006	0.006	25.7
9	0.10	1.03	1.75	1.12	0.07	0.05	0.05	3.48	0.07	0.019	0.046	0.004	0.02	0.007	0.006	37.6

Table 2

Wear rate of the samples

Таблица 2. **Скорость износа образцов**

Sample	Sample weight, g			Number of rotations (V_{rot})	Wear resistance $\Delta m \cdot 10^{-5}$
	before wear, m_1	after wear, m_2	difference		
1	86.0384	85.9819	0.0565	2500	2.26
2	90.1120	90.0561	0.0559	2445	2.29
3	102.6680	102.5870	0.0810	2780	2.91
4	105.5680	105.5010	0.0668	2580	2.59
5	85.6461	85.4218	0.2243	2300	9.75
6	100.0260	99.8323	0.1939	2300	8.43
7	115.5400	115.4650	0.0757	3380	2.24
8	94.4399	94.3375	0.1024	2570	3.98
9	112.6090	112.3920	0.2170	2500	8.68

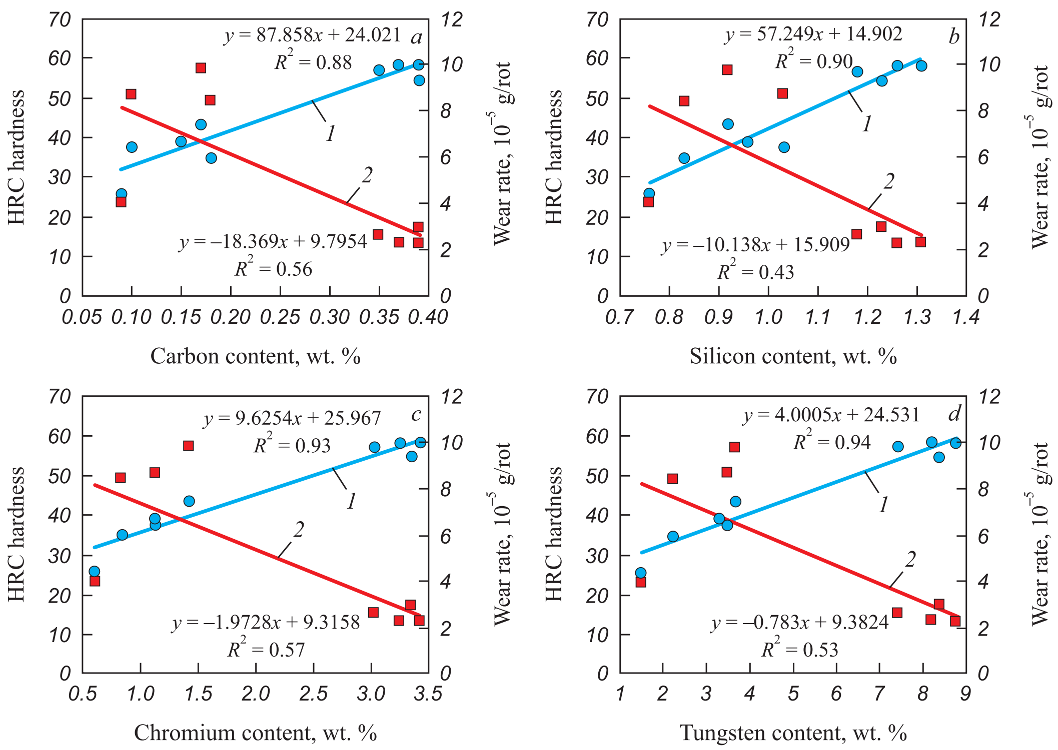

Fig. 3. Dependences of the deposited metal properties on content of carbon (*a*), silicon (*b*), chromium (*c*) and tungsten (*d*): ■ – hardness; ● – wear rate; *1* – linear hardness; *2* – linear wear rate

Рис. 3. Зависимости свойств наплавленного металла от содержания углерода (*a*), кремния (*b*), хрома (*c*) и вольфрама (*d*): ■ – твердость; ● – скорость износа; *1* – линейная твердость; *2* – линейная скорость износа

tion in the concentration of chromium, tungsten, carbon, and silicon. The depicted relationships facilitate the prediction of hardness and wear rate outcomes when modifying the chemical composition of the deposited layers.

Conclusions

A regression analysis was undertaken to investigate the impact of the chemical composition of the deposited layer on both its hardness and wear rate. Consequently, mathematical models were derived to represent the examined operational attributes of the electric arc coating. Notably, the hardness of the deposited metal and its resistance to abrasive wear exhibit an augmentation with an increase in the concentrations of chromium, tungsten, carbon, and silicon.

The findings from these studies offer the potential to formulate strategies aimed at guaranteeing the desired level of operational attributes for the electric arc coating. Furthermore, they can be employed to prognosticate the hardness of the deposited layer and its wear resistance in response to variations in the chemical composition of the deposited metal. Additionally, they enable the anticipation of the operational longevity of rolls coated with wires of the PP-Np-35V9Kh3SF grade.

The mathematical models delineating the hardness of the deposited layer and its wear resistance provide insights that aid in clarifying the mechanism underlying the strengthening and development of protective properties within the surface layers of rolling rolls, achieved through the application of electric arc coatings deposited using flux-cored wires.

References / Список литературы

1. Metlitskii V.A. Flux-cored wires for arc welding and surfacing of cast iron. *Welding International*. 2008;22(11):796–800. https://doi.org/10.1080/09507110802593646
2. Filippov M.A., Shumyakov V.I., Balin S.A., Zhilin A.S., Lehchilo V.V., Rimer G.A. Structure and wear resistance of deposited alloys based on metastable chromium-carbon austenite. *Welding International*. 2015;29(10):819–822. https://doi.org/10.1080/09507116.2014.986891
3. Liu D.S., Liu R.P., Wei Y.H. Influence of tungsten on microstructure and wear resistance of iron base hardfacing alloy. *Materials Science and Technology*. 2014;30(3):316–322. https://doi.org/10.1179/1743284713Y.0000000359
4. Kejžar R., Grum J. Hardfacing of wear-resistant deposits by MAG welding with a flux-cored wire having graphite in its filling. *Materials and Manufacturing Processes*. 2005;20(6):961–976. https://doi.org/10.1081/AMP-200060424
5. Li R., He D.Y., Zhou Z., Wang Z.J., Song X.Y. Wear and high temperature oxidation behavior of wire arc sprayed iron based coatings. *Surface Engineering*. 2014;30(11):784–790. https://doi.org/10.1179/1743294414Y.0000000331
6. Ma H.R., Chen X.Y., Li J.W., Chang C.T., Wang G., Li H., Wang X.M., Li R.W. Fe-based amorphous coating with high corrosion and wear resistance. *Surface Engineering*. 2017;33(1):56–62. https://doi.org/10.1080/02670844.2016.1176718
7. Lim S.C., Gupta M., Goh Y.S., Seow K.C. Wear resistant WC – Co composite hard coatings. *Surface Engineering*. 1997;13(3):247–250. https://doi.org/10.1179/sur.1997.13.3.247
8. Zhuk Yu. Super-hard wear-resistant coating systems. *Materials Technology*. 1999;14(3):126–129. https://doi.org/10.1080/10667857.1999.11752827
9. Hardell J., Yousfi A., Lund M., Pelcastre L., Prakash B. Abrasive wear behaviour of hardened high strength boron steel. *Tribology – Materials, Surfaces and Interfaces*. 2014;8(2):90–97. https://doi.org/10.1179/1751584X14Y.0000000068
10. Deng X.T., Fu T.L., Wang Z.D., Misra R.D.K., Wang G.D. Epsilon carbide precipitation and wear behaviour of low alloy wear resistant steels. *Materials Science and Technology*. 2016;32(4):320–327. https://doi.org/10.1080/02670836.2015.1137410
11. Kirchgaßner M., Badisch E., Franek F. Behaviour of iron-based hardfacing alloys under abrasion and impact. *Wear*. 2008;265(5-6):772–779. https://doi.org/10.1016/j.wear.2008.01.004
12. Hasui A., Morigaki O. *Surfacing and Spraying*. Moscow: Mashinostroenie; 1985:240. (In Russ.).

    Хасуи А., Моригаки О. *Наплавка и напыление*. Москва: Машиностроение; 1985:240.
13. Paton B.E. *Technology of Electric Welding of Metals and Alloys by Melting*. Moscow: Kniga po Trebovaniyu; 2021:769. (In Russ.).

    Патон Б.Е. *Технология электрической сварки металлов и сплавов плавлением*. Москва: Книга по Требованию; 2021:769.
14. Gulyaev A.P. *Metals Science. Textbook for Universities*. Moscow: Metallurgiya; 1986:544. (In Russ.).

    Гуляев А.П. *Металловедение. Учебник для вузов*. Москва: Металлургия; 1986:544.
15. Khrushchov M.M., Babichev M.A. *Abrasive Wear*. Moscow: Nauka; 1970:251. (In Russ.).

    Хрущов М.М., Бабичев М.А. *Абразивное изнашивание*. Москва: Наука; 1970:251.
16. Elagina O.Yu. *Technological Methods of Increasing the Wear Resistance of Machine Parts*. Moscow: Logos; 2009:488. (In Russ.).

    Елагина О.Ю. *Технологические методы повышения износостойкости деталей машин*. Москва: Логос; 2009:488.
17. Tylkin M.A. *Improving the Durability of Metallurgical Equipment Parts*. Moscow: Metallurgiya; 1971:608. (In Russ.).

    Тылкин М.А. *Повышение долговечности деталей металлургического оборудования*. Москва: Металлургия; 1971:608.
18. Danil'chenko B.V. Selection of wear-resistant deposited metal for operation under abrasive wear. *Svarochnoe proizvodstvo*. 1992;(5):31–35. (In Russ.).

    Данильченко Б.В. Выбор износостойкого наплавленного металла для работы в условиях абразивного изнашивания. *Сварочное производство*. 1992;(5):31–35.
19. Gusev A.I., Romanov D.A., Kozyrev N.A., Gromov V.E., Ivanov Yu.F. Structure of weld of wear-resistant surfacing by flux-cored wire of Fe – C – Si – Mn – Cr – Ni – Mo system. *Bulletin of the Siberian State Industrial University*. 2021;(2(36)):3–10. (In Russ.).

    Гусев А.И., Романов Д.А., Козырев Н.А., Громов В.Е., Иванов Ю.Ф. Структура сварного шва износостойкой наплавки порошковой проволокой системы Fe – C – Si – Mn – Cr – Ni – Mo. *Вестник Сибирского государственного индустриального университета*. 2021;(2(36)):3–10.
20. Kozyrev N.A., Titov D.A., Kibko N.V. The study of the influence of the composition of flux-cored wire ПП-Нп-35В9Х3СФ on the properties surfaced roller. *Actual Problems in Machine Building*. 2016;3(3):60–64. (In Russ.).

    Козырев Н.А., Титов Д.А., Кибко Н.В. Изучение влияния состава порошковой проволоки ПП-Нп-35В9Х3СФ на свойства наплавляемого валика. *Актуальные проблемы в машиностроении*. 2016;3(3):60–64.
21. Umanskii A.A., Kozyrev N.A., Titov D.A. The experimental investigations into the influence of the compositions of the cored wires of the C–Si–Mn–Cr–V–Mo and C–Si–Mn–Cr–W–V alloying systems on the build-up mill roll layer structure. *Ferrous Metallurgy. Bulletin of Scientific, Technical and Economic Information*. 2016;(4):74–78. (In Russ.).

Уманский А.А., Козырев Н.А., Титов Д.А. Экспериментальные исследования влияния состава порошковых проволок систем легирования C–Si–Mn–Cr–V–Mo и C–Si–Mn–Cr–W–V на структуру наплавленного слоя прокатных валков. *Черная металлургия. Бюллетень научно-технической и экономической информации*. 2016;(4):74–78.

22. Umanskii A.A., Kozyrev N.A., Titov D.A. Research and development of new compositions of flux-cored wire for surfacing of rolling rolls providing an increase in operational characteristics of the deposited metal. *Proizvodstvo prokata*. 2016;5:43–47. (In Russ.).

Уманский А.А., Козырев Н.А., Титов Д.А. Исследование и разработка новых составов порошковой проволоки для наплавки прокатных валков, обеспечивающих повышение эксплуатационных характеристик наплавленного металла. *Производство проката*. 2016;(5):43–47.

23. Kozyrev N.A., Gusev A.I., Galevskii G.V., Kryukov R.E., Osetkovskii I.V., etc. *Flux-Cored Wire*. Pat. RF 2641590. 2018. (In Russ.).

Пат. 2641590 РФ. МПК[8] B23 K35/36 B 23 K35/36 *Порошковая проволока* / Н.А. Козырев, А.И. Гусев, Г.В. Галевский, Р.Е. Крюков, И.В. Осетковский и др. Заявл. 22.06.2016; опубл. 18.01.2018.

Information about the Authors

Aleksandr A. Usol'tsev, *Cand. Sci. (Eng.), Assist. Prof. of the Chair of Ferrous Metallurgy,* Siberian State Industrial University
ORCID: 0000-0001-6220-7910
E-mail: a.us@rambler.ru

Nikolai A. Kozyrev, *Dr. Sci. (Eng.), Deputy Director of the Scientific Center for High-Quality Steels,* I.P. Bardin Central Research Institute of Ferrous Metallurgy
ORCID: 0000-0002-7391-6816
E-mail: n.kozyrev@chermet.net

Lyudmila P. Bashchenko, *Cand. Sci. (Eng.), Assist. Prof. of the Chair "Thermal Power and Ecology",* Siberian State Industrial University
ORCID: 0000-0003-1878-909X
E-mail: luda.baschenko@gmail.com

Roman E. Kryukov, *Dr. Sci. (Eng.), Assist. Prof. of the Chair of Ferrous Metallurgy,* Siberian State Industrial University
ORCID: 0000-0002-3394-7941
E-mail: rek_nzrmk@mail.ru

Andrei V. Zhukov, *Postgraduate of the Chair of Ferrous Metallurgy,* Siberian State Industrial University
E-mail: Svarka42@mail.ru

Сведения об авторах

Александр Александрович Усольцев, *к.т.н., доцент кафедры металлургии черных металлов,* Сибирский государственный индустриальный университет
ORCID: 0000-0001-6220-7910
E-mail: a.us@rambler.ru

Николай Анатольевич Козырев, *д.т.н., заместитель директора научного центра качественных сталей,* Центральный научно-исследовательский институт черной металлургии им. И.П. Бардина
ORCID: 0000-0002-7391-6816
E-mail: n.kozyrev@chermet.net

Людмила Петровна Бащенко, *к.т.н., доцент кафедры теплоэнергетики и экологии,* Сибирский государственный индустриальный университет
ORCID: 0000-0003-1878-909X
E-mail: luda.baschenko@gmail.com

Роман Евгеньевич Крюков, *д.т.н., доцент кафедры металлургии черных металлов,* Сибирский государственный индустриальный университет
ORCID: 0000-0002-3394-7941
E-mail: rek_nzrmk@mail.ru

Андрей Владимирович Жуков, *аспирант кафедры металлургии черных металлов,* Сибирский государственный индустриальный университет
E-mail: Svarka42@mail.ru

Contribution of the Authors

A. A. Usol'tsev – formation of the main research idea, development of the work methodology, analysis of research results.

N. A. Kozyrev – formation of the main research idea, development of the research plan, setting the tasks, analysis of the research results.

L. P. Bashchenko – collection of the research data, analysis of the research results, preparation of materials for the article.
R. E. Kryukov – development of the research plan, organization of samples testing, collection of the research data, analysis of the research results.
A. V. Zhukov – organization of samples testing, collection of the research data, analysis of the research results.

Вклад авторов

А. А. Усольцев – формирование основной идеи исследований, разработка методологии работы, анализ результатов исследований.
Н. А. Козырев – формирование основной идеи исследований, разработка плана исследований, постановка задач, анализ результатов исследований.
Л. П. Бащенко – сбор данных исследований, анализ результатов исследований, подготовка материалов для статьи.
Р. Е. Крюков – разработка плана исследований, организация испытаний образцов, сбор данных исследований, анализ результатов исследований.
А. В. Жуков – организация испытаний образцов, сбор данных исследований, анализ результатов исследований.

Received 20.04.2022
Revised 31.10.2022
Accepted 12.12.2022

Поступила в редакцию 20.04.2022
После доработки 31.10.2022
Принята к публикации 12.12.2022