Metallophysics and Advanced Technologies
Металофіз. новітні технол.
Metallofiz. Noveishie Tekhnol.
2025, vol. 47, No. 5, pp. 523–533
https://doi.org/10.15407/mfint.47.05.0523
Reprints available directly from the publisher

PACS numbers: 06.60.Vz, 52.77.Fv, 61.50.Ks, 68.35.bd, 68.37.Hk, 81.20.Ev, 81.20.Vj

The Efficiency of Encapsulation of the Functional Component of the Welding Wire Charge on Changing the Structure and Properties of the Metal of the Deposited Layers

V. V. Peremit'ko, V. I. Sukhomlyn, A. V. Yevdokymov,
and A. A. Holyakevych*

Dniprovsky State Technical University,
2 Dniprobudivska Str.,
UA-51918 Kamyanske, Ukraine
**TM.WELTEC LLC,*
15 Kazymyr Malevych Str.,
UA-03150 Kyiv, Ukraine

Based on the conducted experiments, the effectiveness of the application of ferrovanadium from the composition of the powdered wire charge in the form of dispersed particles previously covered with a protective layer of plastic, during arc welding has been proven. We used VELTEK-N620 powdered wire with a diameter of 2.0 mm and experimental wires close in chemical composition to the mentioned standard brand, in which powdered fluoroplastic is used to cover ferrovanadium particles (5 g and 50 g of hydrocarbon per 120 g of ferrovanadium). The addition of coated modifiers to the charge did not worsen the arc burning; spattering of the molten metal during the transition to the liquid bath is reduced to moderate. In the case of surfacing the layers with the use of original flux-cored wires, differences are recorded. When using fluoroplastic in the amount of 5 g per 120 g of ferrovanadium, a decrease in the content of the majority of alloying components is observed due to an increase in the temperature of the bath and the time of its existence. Increas-

---

Corresponding author: Valeriy Viktorovych Peremit'ko
E-mail: vperemitko1965@gmail.ua

Citation: V. V. Peremit'ko, V. I. Sukhomlyn, A. V. Yevdokymov, and A. A. Holyakevych, The Efficiency of Encapsulation of the Functional Component of the Welding Wire Charge on Changing the Structure and Properties of the Metal of the Deposited Layers, *Metallofiz. Noveishie Tekhnol.*, **47**, No. 5: 523–533 (2025). DOI: 10.15407/mfint.47.05.0523

ing the consumption of fluoroplastic to 50 g ensured preservation from evaporation and increased the presence of vanadium and chromium in the applied layer. Pearlite itself is not found in the structure of the deposited layer. The reason is in the increased presence of carbide-forming elements, which bound carbon into carbide compounds. The reduced amount of unbound carbon in the austenite also prevents the formation of martensite on further cooling. The layer of the base-metal bordering the fusion line with a changed carbon content, when using a wire with the addition of 5 g of fluoroplastic to the charge, had a reduced width of 120 μm, and with the addition of 50 g of fluoroplastic, it is much larger, up to 800 μm. The last fact can be considered as the consequence of an increase in the specific of the carbon particles transferred to the metal to be welded, as well as in the increase in the temperature of the melt and the time of its intensive contact with the base during cooling that leads to an increase in the stability of austenite and intensive diffusion of carbon. Due to the diffusion of carbon into the base metal, the ratio between the pearlite and ferrite components changed that gave indirectly grounds for estimating the carbon content in the mentioned layer at the level of 0.4–0.45 wt.%. Carbides are present in large quantities within all zones. Local accumulations of vanadium carbides are found, mainly at the locations of boundaries. In the zones of bainite transformation from austenite, no unidirectional structure is observed that indicates an unchanged crystallographic connection between these components. That is, the orientation of bainite subcrystals is not related to heat dissipation, but to the thermodynamics of the hardening process. The presence of zones of weld metal in the macrodimension with a directional structure is evaluated positively. It is expected that this will help to increase the wear resistance of the surface layer. The lack of crystallographic orientation of bainite is similarly perceived that acquires additional plasticity and resistance to destruction, when external forces are applied.

Key words: arc surfacing, powdered wire, ferrovanadium, covering particles with plastic, high-alloy steel, changing the structure.

На підставі проведених експериментів доведено ефективність внесення під час дугового натоплення ф螺ованадію зі складу шихти порошкового дроту у вигляді дисперсних частинок, попередньо покритих захисним шаром пластику. Застосовували порошковий дріт марки ВЕЛТЕК-Н620 діяметром у 2,0 мм і дослідні дроти, наближені за хемічним складом шихти до згаданої стандартної марки, в яких для покриття частинок ферованадію використовували порошкоподібний фторопласт (5 г і 50 г вуглеводню на 120 г ферованадію). Додавання модифікаторів з покриттям до шихти не погіршило горіння дуги; розбризкування натопленого металу під час переходу у рідку ванну зменшувалося до помірного. У випадку натоплювання шарів із застосуванням ориґінальних порошкових дротів зафіксовано відмінності. З використанням фторопласту у кількості 5 г на 120 г ферованадію спостерігається пониження вмісту переважної більшости леґувальних компонентів через зростання температури ванни та часу підтримки останньої. Збільшення витрати фторопласту до 50 г забезпечило збереження від випаровування та зростання присутности у нанесеному шарі Ванадію та Хрому. У структурі натопленого шару власне перліту не виявлено. Причиною стала підвищена присутність елементів-карбідоутворювачів, які зв'язали Карбон у карбідні сполуки. Зменшений вміст незв'язаного Карбону в аустеніті також запобігає утворенню мартенситу за подальшого охолодження. Суміжний з лінією стоплення шар основного металу зі зміненим вмістом Карбону за використання дроту з додаванням 5 г фторопласту до шихти має зменшену ширину у 120 мкм, а з додаванням 50 г фторопласту — значно більшу, до 800 мкм. Останній факт можна розцінити, як наслідок збільшення питомої частки Карбону, що переходить до металу, який натоплюється, а також зростання температури розтопу та часу його інтенсивного контактування з основою під час остигання, що приводить до збільшення стійкости аустеніту й інтенсивної дифузії Карбону. Через дифузію Карбону в основний метал співвідношення між перлітними та феритними складовими змінилося, що опосередковано дає підстави оцінювати вміст Карбону у згаданому прошарку на рівні 0,4–0,45 мас.%. Карбіди присутні у великій кількості у всіх зонах. Виявляються місцеві скупчення карбідів Ванадію переважно в місцях розташування меж. У зонах бейнітного перетворення з аустеніту не спостерігається однонаправлена структура, що свідчить про незмінний кристалографічний зв'язок між цими складовими. Тобто направленість бейнітних субкристалів пов'язується не з тепловідводом, а з термодинамікою процесу тверді́ння. Наявність у макровимірі зон натопленого металу з направленою будовою оцінюється позитивно. Очікується, це буде сприяти підвищенню опірности поверхневого шару щодо зносу. Аналогічно сприймається й відсутність кристалографічної направлености бейніту, який від цього набуває додаткової пластичности та стійкости щодо руйнування під час прикладання зовнішніх сил.

Ключові слова: дугове натоплення, порошковий дріт, фdenumerovanadій, покриття частинок пластиком, високолеґована криця, зміна структури.

(Received 25 July, 2024; in final version, 26 November, 2024)

1. INTRODUCTION

Intensive wear of contact surfaces is typical for a wide range of machines and mechanisms used in mining, metallurgy, construction, *etc.* The resource of the corresponding parts is provided due to the use in their manufacture of materials with high resistance to various types of abrasive wear. Restoration and/or surface strengthening of working surfaces is performed using chemical-thermal treatment [1], spraying [2–4] and, most often, electric arc surfacing [5].

The experience of using high-alloy high-carbon steels and white cast irons containing strong carbides in the structure is long-standing. Traditionally, the mentioned materials are alloyed with chromium, titanium, molybdenum, and vanadium [6–9]. The result is an increase in the service life of friction contact pairs by 3–15 times compared to ordinary carbon steels [10].

Given the price of the mentioned alloying elements, attention should be paid to the main carbide-forming metals that are chromium, and vanadium, as increasing their content in cast iron to 1% increases wear resistance [11]. Depending on the conditions of crystallisation and the amount of carbon, chromium forms carbides of different compositions (Cr_3C_2, Cr_7C_3, $Cr_{23}C_6$) in alloys. Vanadium stabilises carbides and promotes the formation of long dendrites that intertwine with each other. This influence of vanadium on the structure contributes to an increase in impact toughness and hardness [12].

The nature of the load taken by the parts makes it necessary to combine the material of contact surfaces with high strength and appropriate viscosity [13]. A significant increase in the mechanical and operational properties of steels and alloys can be achieved by modification and microalloying [14]. In the case of electric arc welding, this is carried out by changing the composition of the materials used, in particular, the charge of powdered tapes or wires [15]. The specified scheme, however, leads to inevitable losses of the components of the charge during the passage through the arc gap. Therefore, the improvement of the scheme of adding additional components to the surfacing bath is an important reserve in increasing the efficiency of the application of this particular method of modification.

This study is devoted to the effectiveness of coating the modifier particles with a layer of plastic on the changes in the structure and properties of the Fe–Cr–C alloy layer, which is applied by electric arc welding with flux-cored wire.

It was previously found that the addition of plastic to the composition of the charge of the powdered welding tape causes a slowdown in the crystallisation of the applied layers, the active diffusion of carbon to the areas of crystallisation of primary chromium carbides, and partial depletion of adjacent austenite to cementite [16].

2. EXPERIMENTAL METHODOLOGY

For the experiments, samples of 09G2S low-alloy steel with a size of 150×250×8 mm were used, on which powdered wires, similar in chemical composition to the VELTEK-H620 brands with a diameter of 2.0 mm (the composition of the metal welded into a copper water-cooled crystallizer, wt.%: C—0.8, Mn—3.5, Si—2.5, Cr—4.5, Mo—3.5, V—0.8, B—0.7, Ti—0.9, S—0.015, P—0.017) a wear-resistant metal layer with a thickness of 4–5 mm was deposited. The difference is that the ferrovanadium particles were previously covered with a layer of plastic.

Powdered fluoroplastic (5 g and 50 g of hydrocarbon per 120 g of ferrovanadium) was used for coating. Drying was carried out in an electric oven at 220°C with a holding time of 15 minutes followed by sieving through a 400-μm sieve for uniform distribution and absence of moisture. Later, ferrovanadium with fluoroplastic was added to the other part of the wire charge in the mixer.

For comparison, surfacing was also carried out with a standard VELTEK-N620 wire (without covering the modifiers with plastic).

Electric arc surfacing was carried out in automatic mode ($I_{\text{н}} = 220$–250 A, $U_{\text{д}} = 25$–28 V, $\upsilon_{\text{н}} = 220$ mm/min) in two rounds, on the 'Krystal PNP-2.5' portal type installation.

A spectral analysis of the chemical composition of the deposited metal (SPECTRO MAXx optical emission spectrometer) and metallographic studies of the obtained structures using electron microscopy (REM-106i) were performed.

3. RESULTS AND THEIR DISCUSSION

The addition of coated modifiers to the charge did not impair arc burning, which remained stable for all experimental wires. The transfer of the molten electrode metal ranged from large droplets to jets. Spatter was reduced to moderate when using fluoroplastic as a coating. Surface slag formation is almost absent or insignificant, and the formation of rollers is uniform.

A comparison of the chemical composition of the metal deposited using standard and experimental flux-cored wires (Table 1) revealed the following changes.

In the case of using fluoroplastic to cover particles of the charge components (5 g per 120 g of ferrovanadium, sample No. 2), a decrease in the content of the vast majority of alloying components is observed, which occurred, obviously, due to an increase in the temperature of the bath and the time of its existence. Increasing the consumption of fluoroplastic to 50 g (sample No. 3) ensured preservation from evaporation and increased the presence of vanadium and chromium in the applied

TABLE 1. Chemical analysis of the deposited layer (wt.%).

№	Material brand	C	Mn	Si	P	S	Cr	Ni	Ti	Mo	B	V
1	N-620 without plastic	0.85	2.96	1.57	0.027	0.029	3.25	0.04	0.56	2.12	0.62	0.66
2	N-620 with 5 g of fluoroplastic	0.80	2.77	1.46	0.027	0.033	3.09	0.04	0.51	1.98	0.63	0.51
3	N-620 with 50 g of fluoroplastic	0.86	2.55	1.41	0.026	0.031	3.50	0.04	0.43	1.86	0.57	0.75

layer.

The surfacing performed using VELTEK-N-620 wire and experimental wires based on its charge revealed similar changes.

Even though according to the chemical composition (Table 1), the molten metal must have eutectoid steel (80H3G2M2F); pearlite itself was not found in the structure of the applied layer. The reason was the increased presence of carbide-forming elements that bound carbon into carbide compounds. The reduced amount of unbound carbon in the austenite also prevented the formation of martensite on further cooling.

In the fusion zone, on the side of the base metal, there was undermelting of the metal, followed by the breakdown of austenite by the pearlite mechanism. As a result of complete recrystallization, layering disappeared, and a boundary layer of ferritoperlite structure, typical for steels with C ≅ 0.6 wt.%, was formed. With distance to the depth of the base, the presence of carbon decreases.

When using a standard VELTEK-N-620 powdered wire, a layer of molten metal bordering the fusion line with a width of 0.2–0.3 μm contained bainite packets with individual vanadium carbides (Fig. 1, *a*) due to carbon depletion. Above, on the boundaries of the former austenite grains, carbides fell out, which ensured the formation of a shell structure.

At a distance of 0.85 mm (Fig. 1, *b*) from the fusion line, the deposited layer of the metal had a typical structure of an equilibrium type, carbide precipitates were recorded at the grain boundaries, and low-carbon bainite (≅ 0.3–0.4 wt.% C) was found within the grain boundaries.

When moving away from the fusion zone, the grain size increased, probably due to slower cooling and longer exposure at high temperatures.

It is noteworthy that upon further approach to the surface, at a distance of 4.54 mm (Fig. 1, *c*), there was partial absence of carbide boundaries and a thickening of the latter in certain areas. Morphologically, this fact could be considered as the remains of the dendritic structure that existed at the stage of primary crystallisation.

At a distance of 6.16 mm from the fusion line, the grain became finer; the boundaries were porous and thickened. A significant zonal accumulation of vanadium carbides was recorded. Probably, there were they who caused the increase in grain germs. Particles of carbides gravitated to the boundaries, partially fixing at them.

With further approach to the surface, a similar structure was preserved, but the proportion of dendritic areas increased, which reached a maximum at a distance of 0.76 μm from the surface of the applied layer (Fig. 1, *d*)

In the case of depositing the layers with the use of original flux-cored wires, differences were recorded. The layer of the base metal

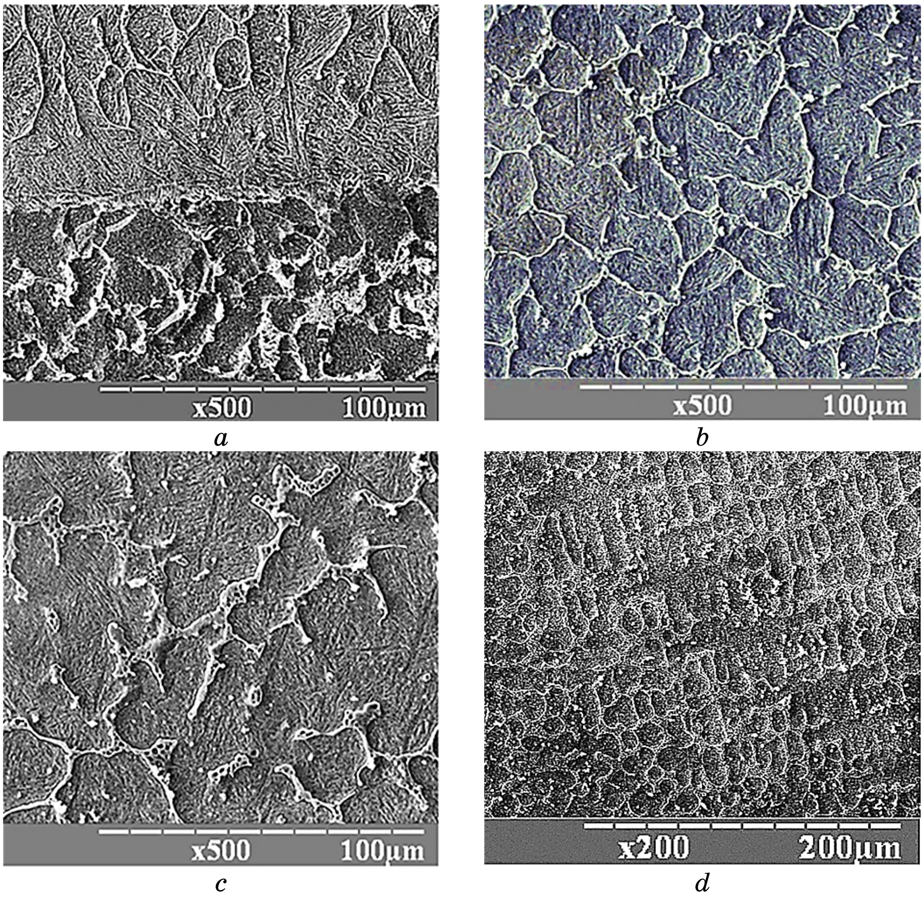


Fig. 1. The structure of the weld metal, at different distances from the fusion line; sample No. 1.

bordering the fusion line with a changed carbon content when using a wire with the addition of 5 g of fluoroplastic to the charge (sample No. 2) had a reduced width (120 μm, Fig. 2, *a*), and with the addition of 50 g of fluoroplastic, it had the maximum width, significantly larger, up to 800 μm (sample No. 3, Fig. 2, *b*, *c*).

The last fact could be regarded as the consequences of an increase in the specific fraction of carbon that passes to the metal that was being welded, as well as an increase in the temperature of the melt and the time of its intense contact with the base during cooling. The above led to an increase in the stability of austenite and intensive diffusion of carbon. Due to the diffusion of carbon into the base metal, the ratio between pearlitic and ferritic components changed, which indirectly gave grounds for estimating the carbon content in the mentioned layer

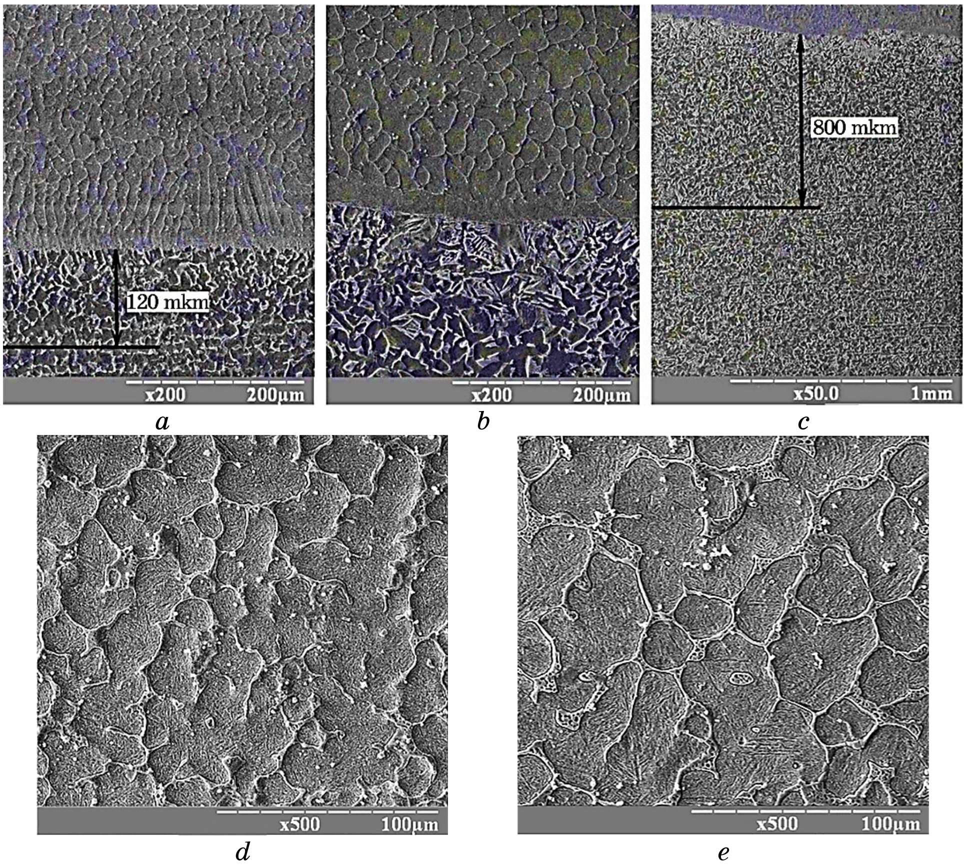
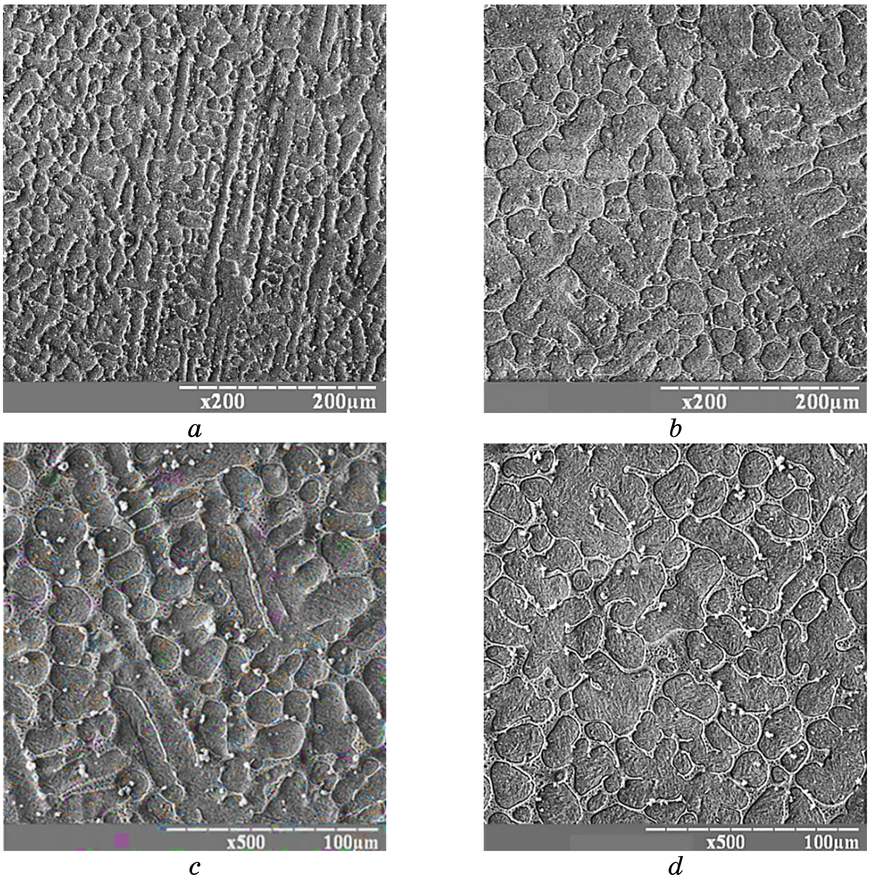


Fig. 2. Thermal influence zone of samples No. 2 (*a*) and No. 3 (*b*, *c*), at a distance of 1.07 mm from the fusion zone of No. 2 (*d*) and No. 3 (*e*).

at the level of 0.4–0.45 wt.% (Fig. 2, *b*). In sample No. 2, where the amount of carbon transferred due to diffusion was much smaller, the width of the layer was also reduced, and the ratio of ferrite and pearlite corresponded to the carbon content at the level of 0.2–0.25 wt.% (Fig. 2, *a*). In the case of a significant addition of plastic (sample No. 3), not only an increase in the presence of carbon in the metal but also the presence of silicon, chromium and vanadium was recorded. This determined the stability of austenite even at a decrease in temperature. As a result, complete recrystallization takes place, which was confirmed by the expansion of the crushed grain zone.

At a distance of more than 1.07 mm from the fusion zone, very weakly directed crystallisation was observed on sample No. 2 (Fig. 2, *d*). The structure was represented by balanced cells, and the thickness of the boundaries was thinned—as a result of the increased cooling rate. At approximately the same distance on sample No. 3, the crystallisation mostly also had a weak directionality, however, the grains located higher acquired a more regular equilibrium shape and were doubled in size (Fig. 2, *e*).

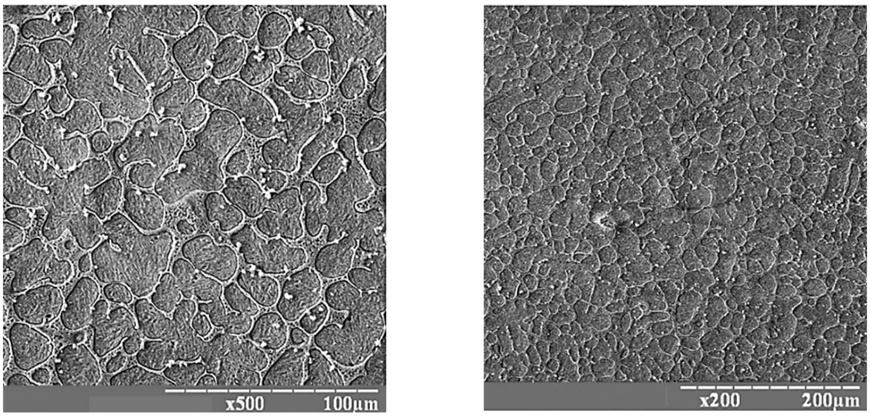
At further distance from the fusion zone ($h \cong 3.0$ mm) on sample No. 2, a distinct directionality of grains was observed (Fig. 3, *a*), weakly repeated at $h \cong 6$ mm (Fig. 3, *c*) and disappearing when approaching the surface at a distance of 1.0 mm (Fig. 3, *d*). Such a picture could be explained by the fact of successive application of two layers. In the case of surfacing of sample No. 3, the mentioned orientation of the crystals was less pronounced, but the size of the grains was twice as large (Fig. 3, *b*). This was probably due to the previously mentioned delayed heat dissipation. At a distance $h \cong 6$ mm from the TIZ in sample No. 3 there was no directionality of crystallisation, but the grain size was the



a *b*

c *d*

Fig. 3. Differences in the structure of the layers deposited with original flux-cored wires (sample No. 2 (*a*, *c*, *e*); sample No. 3 (*b*, *d*, *f*)).



e *f*

Continuation ***Fig. 3.***

same as in sample No. 2 (Fig. 3, *d*), and at a distance of 1.0 mm from the surface in this case the structure became partially dendritic (Fig. 3, *f*).

Carbides were present in large quantities in all zones. This was because they were in a liquid melt. The latter affected the size of the grains, their orientation, and the thickness of the carbide layers. Local accumulations of vanadium carbides were found, mainly at the locations of borders. In the zones of bainite transformation from austenite, no unidirectional structure was observed, which indicates an unchanged crystallographic connection between these components. That is, the orientation of bainite subcrystals was not related to heat dissipation, but to the thermodynamics of the hardening process.

The presence of zones of weld metal with a directional structure in the macro dimension was evaluated positively because it would contribute to increasing the resistance of the surface layer to wear. The lack of crystallographic orientation of bainite is similarly perceived, which acquires additional plasticity and resistance to destruction when external forces are applied.

4. CONCLUSIONS

1. The effectiveness of the scheme for regulating the composition, structure, and properties of the deposited metal due to the preliminary coating of the functional components of the flux-cored wire charge for its application has been experimentally confirmed.
2. It has been established that the addition of plastic to the welding wire charge contributes to the preservation of carbides and causes a thermal effect, slowing down the cooling rate of the heated layer and

increasing the time the metal stays at high temperatures.

3. The use of plastic to form a buffer layer on the particles of the charge ensures the grinding of the structural components of the deposited metal, its saturation with carbon and the formation of a structure favourable for wear resistance, with zones of preserved directionality of dendrites and finely dispersed equilibrium bainite within the grains.

REFERENCES

1. O. G. Cherneta, V. I. Sukhomlyn, and S. V. Ralinichenko, *Mathematical Modeling*, **1**, No. 40: 194 (2019) (in Ukrainian).
2. Yu. S. Borisov, Yu. A. Kharlamov, S. L. Sidorenko, and Ye. N. Ardatovskaya, *Gazotermicheskie Pokrytiya iz Poroshkovykh Materialov* [Gas Thermal Coatings from Powder Materials] (Kiev: Naukova Dumka: 1987) (in Russian).
3. T. Terajima, F. Takeuchi, K. Nakata, S. Adachi, K. Nakashima, and T. Igarashi, *J. Alloys Comd.*, **504**, Iss. 1: 288 (2010).
4. A. V. Hruzevych and V. V. Shvets, *The Paton Welding J.*, **10**: 40 (2021) (in Ukrainian).
5. V. I. Pokhmurskyi, M. M. Student, V. M. Dovhunyk, H. V. Pokhmurska, and I. Y. Sydorak, *Ehlektroduhovi Vidnovni ta Zakhysni Pokryttya* [Electric Arc Restorative and Protective Coatings] (Lviv: National Academy of Sciences of Ukraine, Physical-Mechanical Institute named after G. V. Karpenko: 2005), p. 190 (in Ukrainian).
6. M. V. Kindrachuk, V. Z. Kutsova, M. A. Kovzel, and O. V. Tisov, *Friction and Wear Problems*, **1**, No. 70: 112 (2016).
7. V. A. Masliuk, Ye. S. Karaimchuk, and A. A. Bondar, *The Scientific Technical Journal Metal Science and Treatment of Metals*, **24**, No. 2: 44 (2018) (in Ukrainian).
8. V. I. Tikhonovich, V. P. Havrilyuk, V. V. Tikhonovich, and A. N. Hripachevskiy, *Metallurgy and Metal Processing*, **3**: 16 (2003).
9. Yen Chien Lung, Fu Je Chen, and Yung Ning Pan, *Adv. Mater. Res.*, **859**: 64 (2013).
10. M. N. Brykov, M. I. Andryushchenko, and R. A. Kulikovskiy, *New Materials and Technologies in Metallurgy and Mechanical Engineering*, **2**: 59 (2006) (in Russian).
11. H. Ye. Fedorov, M. M. Yamshynskyi, Ye. O. Platonov, A. Yu. Kuzmenko, and K. S. Radchenko, *Scientific News of NTUU 'KPI'*, **1**: 95 (2009) (in Ukrainian).
12. G. V. Ksendzik, *Primenenie Iznosoctoikikh Chugunov dlya Naplavki Stalnykh Detaley* [The Use of Wear-Resistant Cast Irons for Surfacing Steel Parts] (Kiev: Machinery: 1968) (in Russian).
13. M. M. Brykov, *Metalozn. Obrobka Met.*, **26**: 54 (2020) (in Ukrainian).
14. A. A. Babinets and I. O. Ryabtsev, *The Paton Welding J.*, **10**: 3 (2021) (in Ukrainian).
15. O. P. Voronchuk, O. P. Zhudra, T. V. Kaida, O. V. Petrov, L. M. Kapitanchuk, and I. L. Bogaichuk, *The Paton Welding J.*, **8**: 29 (2022).
16. V. Peremitko, A. Golyakevich, A. Yevdokymov, V. Sukhomlyn, and V. Artemchuck, *Schweissen und Schneiden*, **1–2**: 40 (2024).