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FEATURES OF THE STRUCTURE AND PROPERTIES OF METAL LAYERS DEPOSITED WITH PRE-APPLICATION OF TITANIUM AND BORON CARBIDES

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ABSTRACT

Uneven wearing of working surfaces of parts, operating under friction, is a common cause for beginning of renovation and replacement times. One of the methods to avoid this problem is formation of surfaces of a variable composition and properties by arc surfacing. The work presents comparative analysis of the hardness and structure of the metal, deposited with pre-application of titanium and boron carbides on the processed surfaces. These materials were selected, proceeding from their impact on the deposited metal mechanical properties. The hardness, structure and composition of the deposited metal were studied. Hardness dependence on the heat input and material consumption in individual zones of the bead cross-section was analyzed. Regularities were established between accumulation in the formed beads of material pre-applied on the processed surface and the significance of structural transformations. A similar influence of both the carbides on the deposited metal structure was found. Bead metal hardness is 1.5 times higher at B_4C application, than when TiC is used. X-Ray spectral microanalysis revealed the influence of free carbon, formed as a result of compound decomposition, on structural transformation in the deposited metal. It was found that the largest accumulations of bainite are characteristic for zones with the highest carbon content. It was determined that pre-application of carbides, using the most common surfacing materials, allows producing deposited metal, matching by its properties the metal deposited with PP-Np-152 wire.

KEYWORDS: arc surfacing, solid wire, fused flux, titanium carbide, boron carbide, pre-application, local fixation, hardness, structure

INTRODUCTION

A common method to eliminate the nonuniformity of wear of contact surfaces, operating under the conditions of loads unevenly distributed over the area, is formation of surface layers of variable composition and properties, in compliance with the degree of loss of the initial weld geometry in different sections [1–5]. Such parts, in particular, are ball rolling mill rolls, roller conveyor rolls, supercharger blades, shafts, etc.

The positive effect from pre-deposition or addition of different alloying components during surfacing is known from published data [6–10]. Studying the possibilities of metal microalloying at surfacing with different materials [11] showed that addition of hardening elements or their compounds with carbon and nitrogen in the quantities of up to 0.2 % leads to producing a fine-grained, uniform structure of metal and more uniform distribution of alloying elements. The latter has a positive effect on the metal mechanical characteristics.

In particular, the positive effect of carbide compounds on wear resistance of the deposited layers should be noted, considering the direct dependence between carbide hardness and wear resistance [11–13].

One of the successful examples of realization of surfacing with an essential influence of carbide compounds in the deposited layers is the technology of

producing metal by arc surfacing with formation of carbides of the elements, included into the flux-cored wire charge [12]. The above-mentioned method, however, envisages deposition of metal with the same carbide content over the entire surface, and the process of surface layer formation in such a way will be essentially more complicated. In work [12] metal deposition was performed by PP-AN 192 wire. The structure of such a metal consists of martensite with residual austenite and fine carbide inclusions. The hardness of such a metal is equal to at least *HB* 555.

More over, confirmation of the positive influence of carbide addition on the mechanical properties of the welded joints was obtained [14]. In this work, welding was performed by Sv-08 wire with addition of different modifiers, in particular, also TiC . As a result, weld metal with the continuous bainitic structure was obtained, without preservation of the carbide particles. It was established that titanium carbide increases the endurance limit of the layers by 35 MPa (in 1.08). Also known is application of tungsten carbide as the hardening component [13]. In particular, positive effect of this material on the properties of surface layers, operating under the conditions of gas-abrasive wear was found [14]. In the above-mentioned case, carbides formed from titanium, which is present in the composition of the flux-cored wire charge.

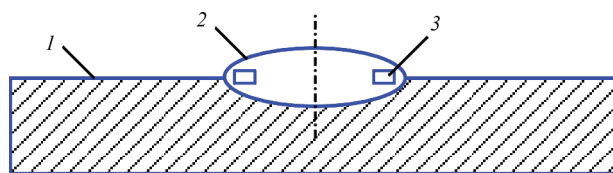


Figure 1. Scheme of additional material application: 1 — sample; 2 — deposited bead; 3 — points of prior fixation of boron or titanium carbides

Considering the high degree of preservation of the components, which can be further added, as well as the possibility of fixation of such materials selectively, in compliance with the real wear pattern, their pre-deposition on the treated surface looks promising [6–8]. Such a scheme also allows performing surfacing with application of widely used electrode wires and fluxes.

Earlier performed investigations showed the positive influence of prior fixation of layers of TiC mixture by GF-021 primer in the form of 2 mm wide bands along the edges of the planned beads [15]. Layers of a variable composition and properties form, and addition of the hardener by the above method allows reaching mechanical inhomogeneity of formation within each bead of zones, differing by their structure and properties from the surfaced base. During performance of the above studies, surface layers were obtained, within which zones of higher and lower hardness alternate with 1.6 times difference of its values. The latter led to a change of the nature of wear and at local increase of hardness the losses surface layer material can be even smaller, than in the case of continuous formation of the deposited layer of homogeneous composition and properties.

The objective of the work was to reveal the significance of the changes in the structure and strength characteristics of individual zones of the deposited layers by their comparative analysis, formed with prior local fixation of the hardeners in the form of carbides.

CONDITIONS OF RESEARCH PERFORMANCE

In view of the above-mentioned influence of carbides on the deposited metal properties, titanium (TiC) and boron carbides (B_4C) were selected for the laboratory study, the hardness of which is equal to 32000 and 36000 MPa, respectively.

Materials were deposited similar to work [15]. Plates from steel 20 of 10 mm thick, 100 mm wide and 100 mm long were used as experimental samples. Deposition was performed by 3 mm Sv-08A wire using AN-348A flux in ADC-1000 welding unit in the following mode: surfacing current — 500 ± 1 A, arc voltage — 30 ± 1 V, surfacing speed — 25–35 m/h,

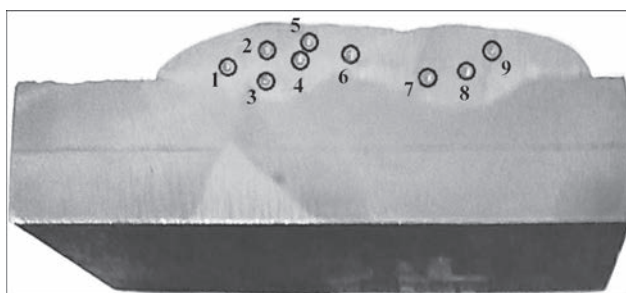


Figure 2. Sample for hardness measurement

eccentricity of material layer deposition — 5–8 mm. The scheme of additional material deposition is given in Figure 1.

Deposition was performed in one layer, overlapping of single beads was equal to 7 mm, deposited layer thickness was 2.5–3.0 mm, overlapping beads were deposited in pairs. Each pair of the beads was applied at a fixed value of heat input.

During experiment preparation a central compositional plan of the second order for two factors was used. Heat input q_h , J/mm and specific material consumption (m_s), g/run. mm were chosen as the influence factors. Hardness in three different areas was selected as the experiment response: along the deposited bead edges, in their lower part and in bead overlapping point. To measure the hardness the samples were cut across into 20 mm wide templates. Measurements were conducted in TK-2 hardness meter in seven points (Figure 2). Metallographic analysis was performed using photomicroscope Neophot 21 and scanning microscope REM-106i. X-ray microspectral analysis was conducted, using electron probe micro-analyzer EPMA-1720. The size of the material area, from which the spectral component of X-ray radiation was obtained for chemical element identification, was equal on average to 70–90 nm on the bead edges and 50–70 nm in bead overlapping zone.

Treatment of experimental results was performed in STATISTICA 7.0 program. Results of metal hardness measurement with addition of TiC and B_4C are given in Table 1.

One can see from the Table that at B_4C addition metal hardness in overlapping area is 1.7 times higher, than in the same area at TiC addition (HB 506 at B_4C addition against HB 302 at TiC addition) under the condition of constant heat input, 1314 J/mm. This is attributable to higher stability of B_4C under the conditions of moderate thermal impact, higher intrinsic hardness and, consequently, greater presence of carbide particles in the metal.

Figure 3 gives the dependence of hardness change in overlap zone (area of adding different carbides).

One can see from Figure 3 that maximum increase of hardness in the bead overlap zone at TiC addi-

Table 1. Results of hardness measurement in bead deposition zones

Sample number	Heat input q_{run} , J/mm	Specific consumption m , g/ $_{run}$, mm	$HB_{on\ bead\ periphery}$ (TiC)	$HB_{in\ overlap\ zone}$ (TiC)	$HB_{lower\ part}$ (TiC)	$HB_{on\ bead\ periphery}$ (B_4C)	$HB_{in\ overlap\ zone}$ (B_4C)	$HB_{lower\ part}$ (B_4C)
1	1848	0.032	255	293	241	298	333	269
2	1848	0	192	187	187	192	187	187
3	1314	0.032	293	302	262	432	506	403
4	1314	0	192	187	187	192	187	187
5	1536	0.032	248	255	277	325	354	373
6	1536	0	192	187	187	192	187	187
7	1848	0.016	293	302	262	285	306	255
8	1314	0.016	241	262	241	432	420	255
9	1536	0.016	192	269	255	246	373	246

tion, is observed at heat input values in the range of 1600–1800 J/mm and at specific hardener consumption of $3.2 \cdot 10^{-2}$ g/mm. At B_4C application hardness increase is recorded at somewhat smaller heat input values — 1400–1700 J/mm, and at the same losses of the hardener. When 1700 J/mm is exceeded, a lowering of hardness is observed. At the same time, addition of titanium carbide allows increasing the heat input to a maximum, assigned for the experiment (1848 J/mm) without causing any lowering of hardness. This is attributable to a higher melting temperature of TiC (3100 °C), as well as carbon saturation due to carbide decomposition. The influence of heat input on hardness is characterized by that the heat input is reduced at reduction of energy input, and, consequently, material burnout becomes smaller that promotes hardness increase.

Proceeding from the conducted studies, the influence of local addition of carbides on metal properties directly in the points of their addition, does exist. Owing to a short time of liquid pool existence and imperfect mixing of the melt, the hardener particles are predominantly preserved in the points of their previous fixation, causing 2.7 times increase of hardness there in case of boron carbide addition, compared to the central zone of the beads (HB 506 against HB 187) and 1.5 times on the edge, at a similar comparison (HB 432 against HB 293). At TiC addition in the

overlapping area the difference is 1.6 times (HB 302 against HB 187), and 1.5 times on the edges (HB 293 against HB 192).

Thus, local addition of TiC to the periphery of the beads at maximum distance from the arc, allowed increasing the hardness in the area of addition by HB 115, whereas in work [13] hardness increased by HB 7.

Maximum value of hardness obtained in the overlap zone at B_4C addition (HB 506) is close to that of metal deposited with PP-AN 192 wire (HB 555) [12]. It confirms the possibility of formation of a high-strength metal with local addition of carbides without application of costly surfacing materials and potentially with smaller consumption of the hardener.

Metallographic analysis of the deposited metal revealed a structure in the overlap zones and on bead edges, which is characteristic for the case of higher carbon content (Figure 4). Maximum changes are observed in overlap zones, that is accounted for by the fact of the greatest presence of the hardener. In case of TiC addition the structure consists of bainite, martensite and ferrite. Considering the fact that ferrite forms the deposited metal base, presence of bainite, most probably, points to ferrite saturation by carbon from added carbide, as a result of thermodynamic decomposition of the latter. Now martensite, in its turn, may be the consequence of carbon decomposition in iron and additional alloying with manganese from

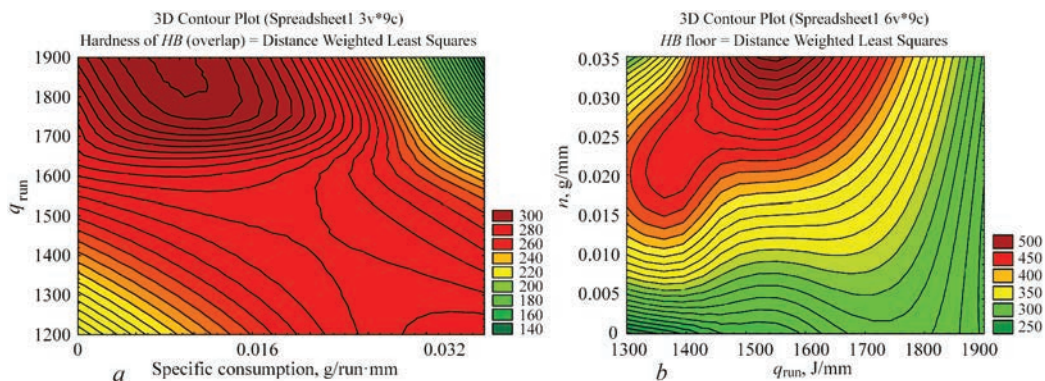


Figure 3. Dependence of metal hardness in bead overlap area on the heat input and specific consumption: *a* — at TiC addition; *b* — at B_4C addition

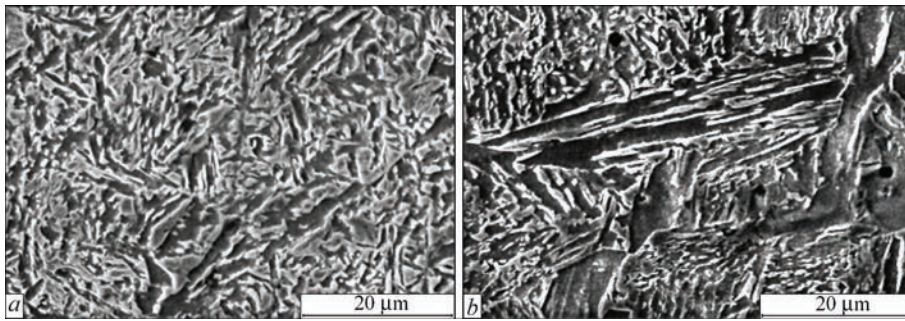


Figure 4. Metal microstructure in areas of separate bead overlapping: *a* — with TiC addition; *b* — with B₄C addition

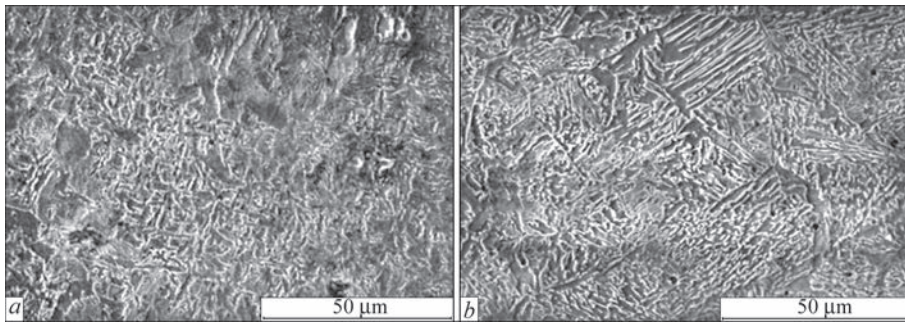


Figure 5. Metal microstructure on bead edge: *a* — with TiC addition; *b* — with B₄C addition

AN-348A flux that enhances the overall stabilization of austenite. Bainite is presented by compact in size and densely located areas within the austenite grains (Figure 4). This way, local TiC addition promotes less decomposition of the compound that is confirmed by single unsaturated areas of ferrite, while the structure produced in work [13] is continuous bainite.

The structure in the point of bead overlapping at B₄C addition (Figure 4) also is a combination of ferrite and bainite with carbide particle clusters, predominantly in ferrite areas. Bainite areas, in their turn, are much less in quantity in the case of B₄C addition, compared to a similar case with TiC. This observation, as well as an accumulation of boron carbides, is attributable to a different kinetics of formation of morphological features of the final structures, compared to TiC addition.

An increase of the number of ferrite areas with reduction of bainite presence is observed at the edge of the bead, deposited with TiC addition (Figure 5, *a*) without overlapping (where there is less hardener

than in the overlap zones). This may be an indication of less significant saturation of ferrite by carbon. In a similar area, at B₄C addition (Figure 5, *b*), much less carbide particles, compared to the overlap zone, increase in bainite areas, and reduction of ferrite, are found. The latter, apparently, is attributable to greater decomposition of added material in this zone.

X-ray microspectral analysis of samples with TiC deposition was performed for a more detailed study of the influence of titanium carbide on the deposited metal structure and properties.

All the three variants of deposition of layers with hardener are given in Figure 6. One can see that on side beads the area of ferrite sections is greater than that of ferrite sections in the bead overlap zone. Bainite structures in bead overlap zone have a greater dispersion and signs of rapid crystallization: compact zones with uniform orientation of the bainite components are recorded. On side beads the bainite structure corresponds to longer time and lower rate of the solidification process.

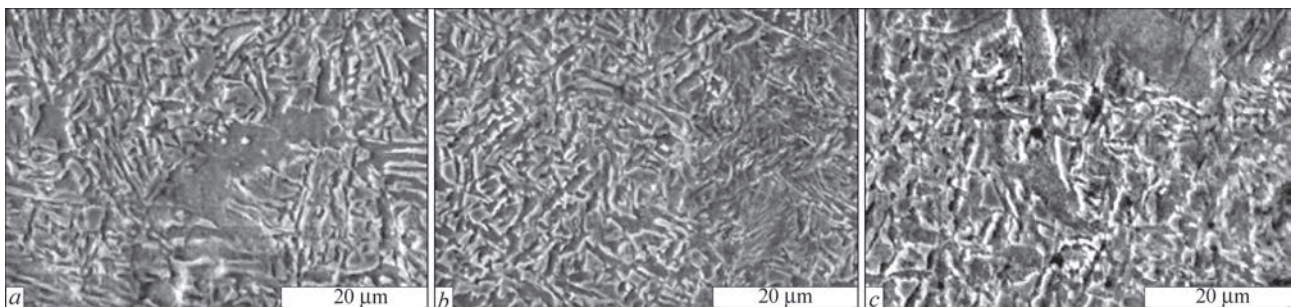


Figure 6. Metal microstructure in the cross-section of the beads, deposited with TiC addition: *a* — bead left edge; *b* — bead overlap zone; *c* — bead right edge

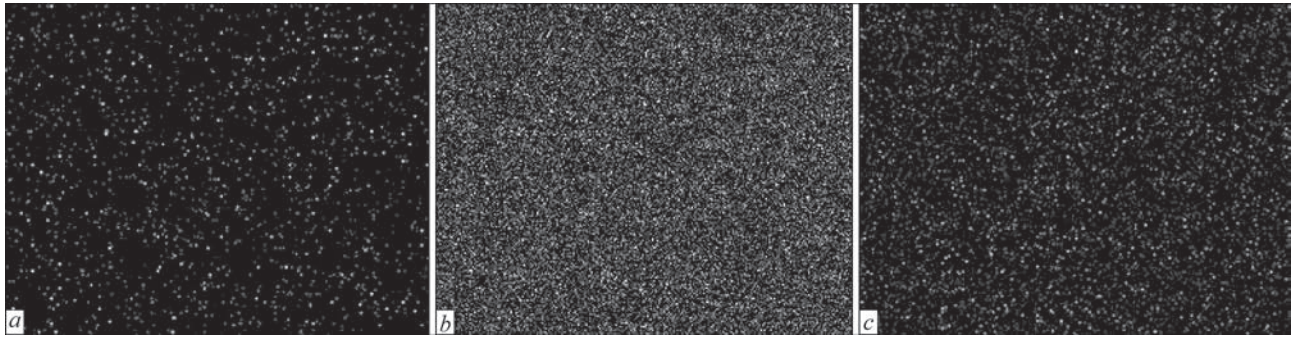


Figure 7. Ti distribution over the deposited bead cross-section: *a* — bead left edge; *b* — bead overlap zone; *c* — bead right edge

Table 2. Weight fraction of elements in the metal of different zones of surfacing with titanium carbide, %

Chemical element	Left bead		Overlap zone		Right bead	
	Ferrite	Bainite	Ferrite	Bainite	Ferrite	Bainite
Si	0.81–0.93	0.75–0.90	0.60–0.79	0.72–0.75	0.77–0.85	0.91–0.94
Mn	1.48–1.75	1.29–1.56	1.66–1.75	1.61–1.72	1.63–1.90	1.50–1.91

Figure 7 shows titanium distribution in the metal, deposited using titanium carbide. Arrangement of distribution patterns corresponds to structure patterns in Figure 6. One can see that in all the studied zones titanium distribution is relatively uniform. On bead edges, however, the overall quantity of titanium is smaller, and the dimensions of individual particles are larger.

Considering that titanium has a higher affinity to carbon, compared to iron (and other metals from the melt composition), as well as a high temperature of carbide formation in the surfacing pool, we can assume that the titanium carbide nuclei are exactly the centers of austenite crystallization, and later on, at austenite decomposition they are the centers of bainite and ferrite crystallization. Thus, titanium is exactly the main element of structure formation in different locations in the beads.

Distribution of the main chemical elements in the deposited metal composition is shown in Table 2.

Si and Mn concentration is rather high due to their presence in the base metal of the samples, in the surfacing wire and in the composition of AN-348A flux. Manganese improves austenite stability, and, thus, also the probability of shear structure formation. Silicon in the composition of ferrite and bainite enhances the hardness of these structural components. An almost the same Mn and Si concentration in ferrite and bainite structure is attributable to a feature of bainite transformation. During the latter, just carbon redistribution occurs and no redistribution of alloying elements takes place.

Thus, from the two considered carbides B_4C can be regarded more efficient in terms of metal hardness increase. This is due to the fact that despite the lower thermodynamic stability of the compound, B_4C

ensures hardness values on average 1.4 times higher than TiC does.

CONCLUSIONS

1. A greater effectiveness of local pre-deposition of B_4C on the surface for arc surfacing, compared to TiC, was experimentally established: at 1314 J/mm heat input and B_4C specific consumption of $3.2 \cdot 10^{-2}$ g/mm, 2.7 times higher metal hardness is recorded. For metal with B_4C addition at heat input increase up to 1848 J/mm, the hardness is on average 1.4 times higher than with TiC participation.

2. Under the same heat input conditions and quantity of added hardener, the structure of metal of the deposited layers does not essentially differ. In layers with different hardeners, a ferrite structure with bainite areas is observed, that develops due to saturation with carbon, which forms as a result of carbide decomposition. In the case of B_4C hardening, a carbide cluster is recorded, predominantly in ferrite areas. Under the conditions of moderate heat input, boron carbide is more stable, than titanium carbide.

3. X-ray microspectral analysis of metal, deposited with TiC addition, confirmed an essential influence of free carbon on structural transformations in the deposited metal. In particular, it was found that in the bead overlapping zone TiC carbides of the size of several tens of nanometers serve as nuclei for crystallization and growth of a more dispersed bainite, compared with other zones of the beads.

4. Hardness of metal deposited with Sv-08A solid wire with further addition of boron carbide, is close to the values, characteristic for the case of application of PP-AN 192 flux-cored wire (*HB* 506 against *HB* 555) that confirms the good prospects for application of the

proposed scheme of further addition of carbides into the deposited metal layer.

REFERENCES

- Leshchinskiy, L.K., Gulakov, S.V., Stepnov, K.K., Nosovskiy, B.I. (1985) *Newly designed hardfaced rolls improve rolling mill efficiency*. Ed. by P.V. Gladkiy. Kyiv, Ukraine [in Russian].
- Ivanov, V.P. (2019) *Theoretical and technological bases of increasing the efficiency of electric arc surfacing on the basis of modeling of formation of welding pool*: Syn. of Thesis for Dr. of Tech. Sci. Degree. PDTU, Mariupol, Ukraine [in Russian].
- Yaryza-Stetsenko A.V. (2012) *Increasing of arc hardfacing technology with variable chemical composition by its alloying from flux*: Syn. of Thesis for Cand. of Tech. Sci. Degree. DMA, Kramatorsk, Ukraine [in Russian].
- Kragelskiy, I.V. (1968) *Friction and wear*. Moscow, Mashinostroenie [in Russian].
- Chigarev, V.V., Ivanov, V.P., Psaryova, I.S. (2003) Increasing of details and parts performance by hardfacing of heterogeneous layer. *Zakhyst Metalurgiynykh Mashyn vid Polomok*, **7**, 234–237 [in Russian].
- Schenfeld, V.Y. (2014) *Increasing of wear resistance of steel parts by surfacing with the use of carbon fiber materials*: Syn. of Thesis for Cand. of Tech. Sci. Degree. VDTU, Vinnytsya, Ukraine [in Russian].
- Peremitko, V.V. (2014) Wear resistant arc surfacing over the layer of alloying charge. *The Paton Welding J.*, **8**, 54–57.
- Peremitko, V.V., Panfilov, A.I. (2017) Arc surfacing of layers of metal of varying composition and hardness. *The Paton Welding J.*, **7**, 38–42. DOI: <https://doi.org/10.15407/tpwj2017.07.08>
- Kuznetsov, V.D., Stepanov, D.V. (2015) Structure and properties of welded joint's metal modified by nanooxides. *The Paton Welding J.*, **11**, 10–16.
- Kuznetsov, V.V., Stepanov, D.V. (2015) Wear resistant surfacing with feeding of nanopowders to weld pool. *The Paton Welding J.*, **5–6**, 52–56.
- Babinets A.A., Ryabtsev I.O. (2021) Influence of modification and microalloying on deposited metal structure and properties (Review). *The Paton Welding J.*, **10**, 3–10. DOI: <https://doi.org/10.37434/tpwj2021.10.01>
- Ryabtsev, I.A., Panfilov, A.I., Babinets, A.A. et al. (2015) Structure and abrasive wear resistance of deposited metal hardened with carbides of different types. *The Paton Welding J.*, **5–6**, 78–82.
- Zhudra, A.P. (2014) Investigation of wear resistance of composite alloys under the conditions of gas-abrasive wear at elevated temperatures. *The Paton Welding J.*, **11**, 28–31.
- Peremitko, V.V., Kolomojets, I.V., Sukhomlin, V.I. (2019) Effect of preliminary application of alloying powders on the structure and hardness of deposited metal. *The Paton Welding J.*, **9**, 30–33. DOI: <https://doi.org/10.15407/tpwj2019.09.05>
- Peremitko, V.V., Kolomojets, I.V. (2021) Influence of orientation of zones of higher hardness of composite layers on their resistance to wear. *Archives of Materials Science and Engineering*, **110**, 59–71.

CONFLICT OF INTEREST

The Authors declare no conflict of interest

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