

## IMPROVEMENT OF ABRASION RESISTANCE OF PRODUCTION EQUIPMENT WEAR PARTS BY HARDFACING WITH FLUX-CORED WIRES CONTAINING BORON CARBIDE/METAL POWDER REACTION MIXTURES

*Oleksandr IVANOV, Pavlo PRYSYAZHNYUK, Dmytro LUTSAK, Oleh MATVIENKIV  
Ivano-Frankivsk National Technical University of Oil and Gas*

*Vicktor AULIN  
Central Ukrainian National Technical University*

### Abstract:

In this work was established that serial traditional hardfacing materials based on the Fe-Cr-C system are not effective for improvement of abrasion resistance of elements of equipment for production of bricks, solid fuel briquettes and for restoration of augers, due to the fact that this equipment works at significant specific and cyclic loads. Features of the coarse-grained structure of Fe-Cr-C based coatings leads to intensive abrasive wear. The aim of this study was to increase a durability of that equipment by using of flux cored electrodes with reaction components of Ti, Cr, Mo, B<sub>4</sub>C and their combinations to provide synthesis, which leads to fine-grained structure of refractory borides and carbides and their solid solutions with increased hardness. Structure of the hardfacing coatings were investigated by method of metallography, scanning electron microscopy (SEM), electron backscatter diffraction (BSD) mode and energy dispersive X-ray spectroscopy (EDS). Temperature dependences of equilibrium phase amount of the hardfacing materials were calculated by the CALPHAD technique, using JMatPro software. It was investigated that the offered materials are characterized by higher wear resistance at high specific and cyclic loads in comparison with serial production high-chromium hardfacing materials (Lastek, ESAB, Paton IEW). It was established that the abrasion wear resistance at high specific and cyclic loads depends mostly of formation of the structure of hardfacing material, and not the hardness. Also, using of powders of pure metals and their combination as reaction mixture for FCAW leads to fine structure which contains of refractory borides and carbides and their solid solutions.

**Key words:** *flux cored electrodes, abrasion resistance, refractory borides, solid solutions, high specific loads*

### INTRODUCTION

Today the objective of increasing wear resistance of equipment that works in environment of intense abrasion wear [1], as well as under high specific and cyclic loads is relevant and important. Such equipment includes augers for pressing of wood wastes, equipment for production of bricks, solid fuel briquettes, etc. Hardfacing using flux cored arc welding (FCAW) is widely used way to improve the resistance to abrasion wear by obtaining high alloying element content in the surface layers [2, 3]. The most commonly employed hardfacing materials based on the Fe-Cr-C system due to their high hardness, good corrosion and wear resistance [4], such materials include the modern serial production electrodes manufactured by Lastek, ESAB, Paton IEW, etc. However, traditional serial production materials, based on Fe-Cr-C system, are characterized with low resistance in the conditions of abrasion wear under high specific and cyclic loads. Therefore, there is a problem of creating alternative economically expedient

systems for restoring equipment wear parts that work in such conditions.

### LITERATURE REVIEW

The microstructure of the Fe-Cr-C hardfacing coatings usually consists of primary coarse M<sub>7</sub>C<sub>3</sub> – type chromium carbide, eutectic carbides and Fe – based matrix [5]. Chromium carbides in surface layer usually are not uniformly distributed in iron matrix due to formation of the M<sub>7</sub>C<sub>3</sub> skeleton promotes brittle fracture especially during multilayer hardfacing [6, 7].

Advanced studies of low stress abrasion resistance for wide range of iron-based hardfacing materials based on the Fe-Cr-C system were conducted by Kotecki and Ogborn [8]. They concluded that the microstructure, not hardness, is the most important factor determining abrasion resistance and that the most desirable microstructure consists of primary carbides and austenite-carbide eutectic. Such type of the microstructure often presents

in metal matrix composites based on refractory transition metal compounds [9, 10].

In order to increase wear resistance some researchers have completely replaced chromium in hardfacings with another carbide forming elements such as Ti, V, Mo [11, 12]. Wang have deposited surface layers by shielded manual arc welding (SMAW) using stick electrodes coated with flux containing mixture of ferroalloys. Microstructural characterization studies showed the presents of dispersed and uniformly distributed cuboid-shaped complex carbides particles in the matrix.

The presence of uniformly finally dispersed hard phase in iron-based matrix can be obtained using Ti – alloyed flux cored materials. It may be possible to incorporate such structure of hard carbide ceramic particles into a metal matrix to produce metal matrix composites (MMCs) by the “*in-situ*” synthesis technique, whereby carbide reinforcements are produced in situ in a metal matrix during melting and solidification. that can withstand high abrasive wear environments [13]. Jilleh [14] reported that additions of Ti to the Fe-Cr-C based flux – cored wire prevents chromium carbides formation due to the formation of uniformly dispersed TiC inclusions in the steel matrix. Similar features of TiC grains formation were observed after FCAW with flux of Fe-Cr-C-B system with Ti additions [15].

For alloying the Fe-Ti-C system researchers more often uses Mo [16], Nb [17] and V [17]. Presence of boron in the system is also advisable, that will provide the formation of borides of and other elements. Titanium borides are characterized with high hardness (~ 32 GPa), and their low solubility in Fe (~ 1 wt. %) [18] will provide heterogenous structure, where metal matrix and carbides particles would work in conditions of dynamic loads.

In the present investigation the aim was to achieve a hardfacing layer with high volume fraction of titanium refractory compounds (TiC and TiB<sub>2</sub>) dispersed in ductile Fe-based matrix using FCAW wire containing reaction powder mixture of titanium and boron carbide. Also, to investigate the effect of Cr, Mo metal additives on the Fe-Ti-B-C system.

For hardfacing coating that works in conditions of intense abrasion wear such parameters as the microstructure, type of matrix, distribution of carbides, their size, shape and hardness are most important [19].

## METHODOLOGY OF RESEARCH

The FCAW wire was manufactured by placing mixture of fine (particles size ~ 20 μm) powders of initial components into low carbon 08 kp steel (GOST 503-81) with size 0.5 × 20 mm sheath through rolling. The schematic wire cross section is shown in Fig. 1.

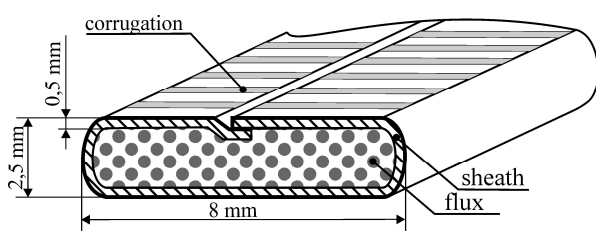
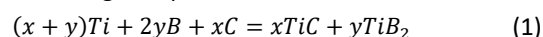


Fig. 1 Schematic drawing of the cross-section of a FCAW wire

According to the work [20], TiC and TiB<sub>2</sub> forms during the self-propagating high-temperature synthesis between Ti, B and C according to equation:



This equation can be transformed according to starting components:



As initial components metal powder of Ti, Cr and Mo were used, as well as B<sub>4</sub>C powder. The mass fraction of initial components for each sample shown in Table 1.

Table 1  
Nominal composition of specimen initial components

Specimen No.	Compositions, wt.%			
	B <sub>4</sub> C	Ti	Mo	Cr
1	27.8	72.2	-	-
2	20.392	26.4	53.11	-
3	26.948	35.01	-	38.037
4	16.102	-	83.88	-
5	26.167	-	-	73.83

The filling coefficient ( $K_f$ ) of the wire was calculated as the mass ratio between the flux and cored wire according to the formula:

$$K_f = \frac{G_{pow}}{G_{el}} \cdot 100 \% \quad (3)$$

where:

$G_{pow}$  – weight of the initial powder,

$G_{el}$  – weight of filled electrode wire.

Control of the  $K_f$  was carried out by weighing not less than three electrodes, with the weighing accuracy 0.01 g.

In present study the filling coefficient was approximately 25%, so the chemical composition of a wire was as shown in Table 2.

Table 2  
Nominal compositions of specimen wires

Specimen no.	Compositions, wt.%				
	B <sub>4</sub> C	Ti	Mo	Cr	Fe
1	6.95	18.05	-	-	bal.
2	5.098	6.6	13.278	-	bal.
3	6.737	8.75	-	9.51	bal.
4	4.026	-	20.97	-	bal.
5	6.54	-	-	18.458	bal.

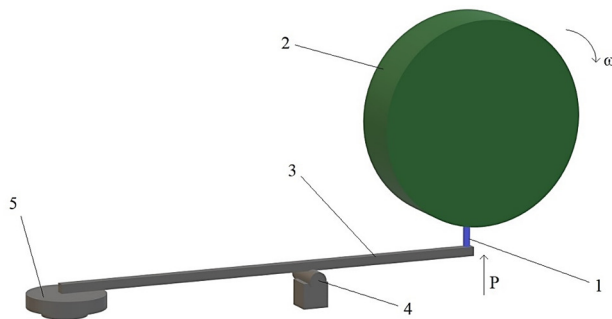
According to the Table 2 temperature dependences of equilibrium phase amount of the hardfacing materials were calculated by the CALPHAD technique, using JMatPro software.

To assure the dryness of the initial powders before weighing they were dried in the SNOL-type drying cabinet at 120°C for 1.2 h. Mixing of the powder components was performed on a laboratory gravity drum mixer with an inclined axis of rotation for 1 h. After mixing the mixture was additional dried at 120°C for 0.5 h to prevent influence of air humidity on bulk properties. Before welding electrode wire was cut into 420 mm length electrodes.

The hardfacing was carried out on 3 sp steel (GOST 380-2005) substrate by means of manual FCAW under direct current with a reverse polarity using VDU-506 rectifier.

The welding parameters were as follows: welding current 160-180 A, arc voltage 30-32 V. Cooling was carried out on air at 20°C.

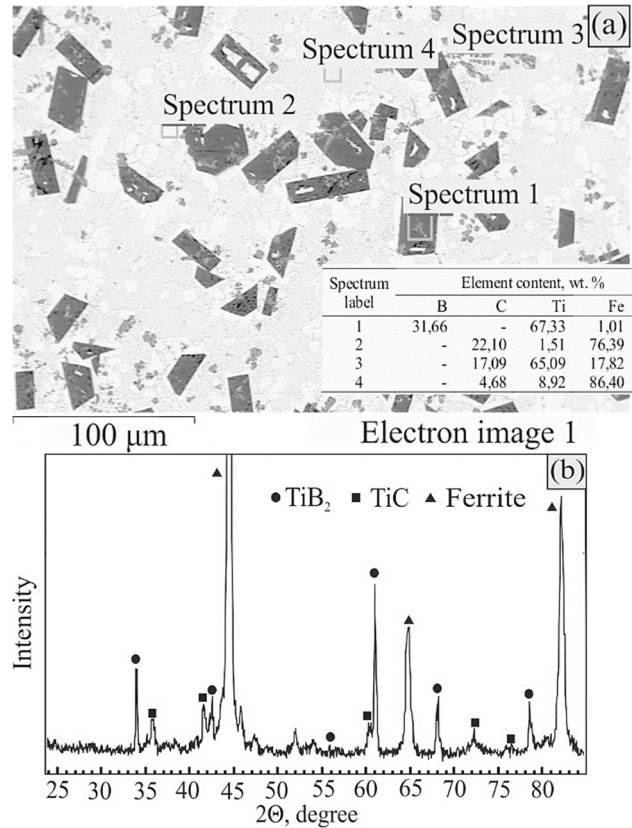
Microstructure was observed with a scanning electron microscopy (SEM) using ZeiSS EVO 40XVP electron microscope, electron backscatter diffraction (BSD) mode, energy dispersive X-ray spectroscopy (EDS). Also, the structure was observed with PMT-3 hardness meter, by camera added to the lens. The hardness was measured by means of the average measurements taken from the top surface of the hardfacing layers by Rockwell method, scale "A". The wear testing with fixed abrasive was carried out without lubrication at room temperature using a wear tester machine, as presented in Fig. 2. The ring material of the wear couple was 64CF46L7V (GOST 52781-2007). The load in the contact area was of 3.5 kN, a sliding speed of 2 m/s and a sliding distance of 800 m. The test specimens were machined as cylinders with radius 10 mm.



**Fig. 2** A schematic diagram of wear testing: 1 – specimen; 2 – abrasive wheel; 3 – support; 4 – lever; 5 – weight

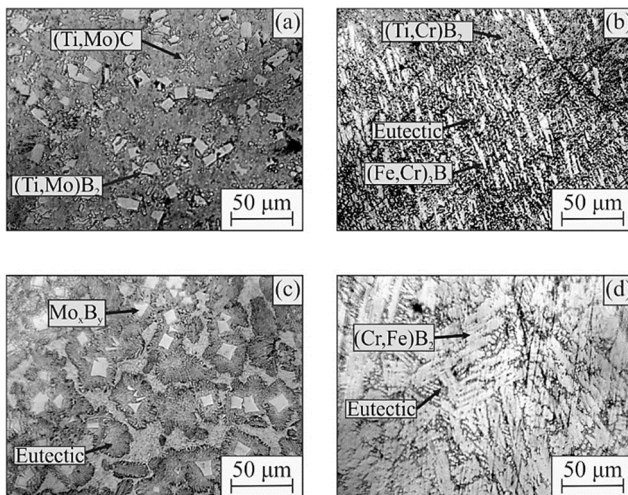
## RESULTS OF RESEARCH

As shown in Fig. 3a, microstructure of specimen № 1 consists of three phases, with respect to used method of structural investigations (BSD), where phase density map is proportional to the brightness map. The dark phase (with lowest density) represented by large (20-60 μm) hexagonal-shaped and uniformly distributed particles with high content of boron and titanium. According to the XRD-pattern analysis Fig. 3b this phase was matched with  $TiB_2$  lines. The grey phase crystallizes in form of asymmetric dendritic grains, which partially penetrated into  $TiB_2$  grains and as a rods in rod-like eutectic structure. This phase generally enriched with Ti and C and due to XRD results was identified as non-stoichiometric titanium monocarbide ( $TiC$ ). The bright Fe-rich phase coexists with  $TiB_2$  and  $TiC$  in form of separated well-rounded grains, a layer surrounding  $TiB_2$  particles and matrix of rod-like eutectic was determined by X-ray diffraction as ferrite.

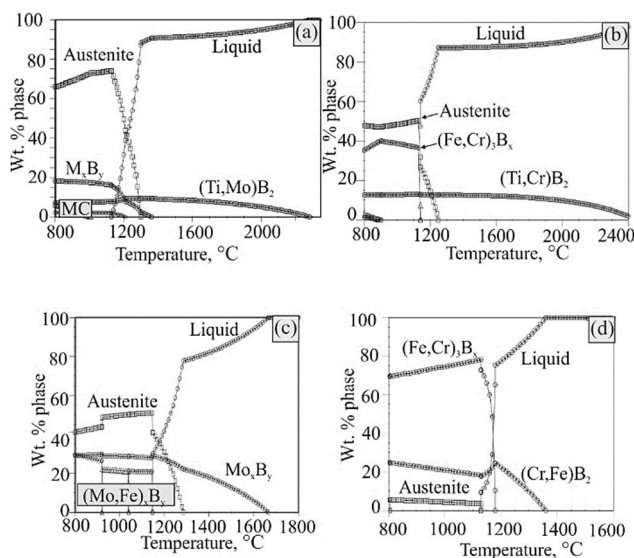


**Fig. 3** Detailed SEM+EDS analysis of the microstructure of specimen 1 (a) and corresponding X-ray diffraction pattern (b)

As shown in Fig. 4a,b the addition Mo and Cr in equimolar ratio Me/Ti to the Ti-B<sub>4</sub>C system significantly affects the peculiarities of structure formation mainly due to the appearance of new phases and significantly grain refinement of MeB<sub>2</sub> phase. After Mo addition Fig. 4a the mean grain size of MeB<sub>2</sub> decreases in approximately two times with remaining of hexagonal grain shape, however MC-based phase does not undergo significant changes in size and shape. It can be caused by significantly higher solubility of Mo in  $TiB_2$  which tends to formation (Ti, Mo)<sub>2</sub> solid solution with increased hardness. As shown in Fig. 5a crystallization of (Ti, Mo)<sub>2</sub> starts at 2300°C and ends at 1600°C, and after that in solid state its amount is unchanged. Cr addition Fig. 4b leads to significant changes in size and shape of structure, consists of (Ti, Cr)<sub>2</sub> grains and (Fe, Cr)<sub>3</sub>B<sub>x</sub>+γ-Fe eutectic matrix, which forms at about 1200°C (Fig. 5b). Specimen based on Fe-Mo-B<sub>4</sub>C system (Fig. 4c) consists of hexagonal-shaped Mo<sub>x</sub>B<sub>y</sub> grains which are embedded in an eutectic matrix of (Mo,Fe)<sub>x</sub>B<sub>y</sub>+γ-Fe. Such eutectic forms at about 1200°C (Fig. 5c). Specimen based on Fe-Cr-B<sub>4</sub>C system (Fig. 4d) has solidified in coarse structure of (Cr, Fe)<sub>2</sub> phase which are embedded in (Fe, Cr)<sub>3</sub>B<sub>x</sub>+γ-Fe eutectic (Fig. 5d) matrix.



**Fig. 4 Results of optical microscopy analysis of hardfacing weld deposits with different combinations of Me/B<sub>4</sub>C systems: Fe-Ti-Mo-B<sub>4</sub>C specimen 2 (a); Fe-Ti-Cr-B<sub>4</sub>C specimen 3 (b); Fe-Mo-B<sub>4</sub>C specimen 4 (c); Fe-Cr-B<sub>4</sub>C specimen 5 (d)**

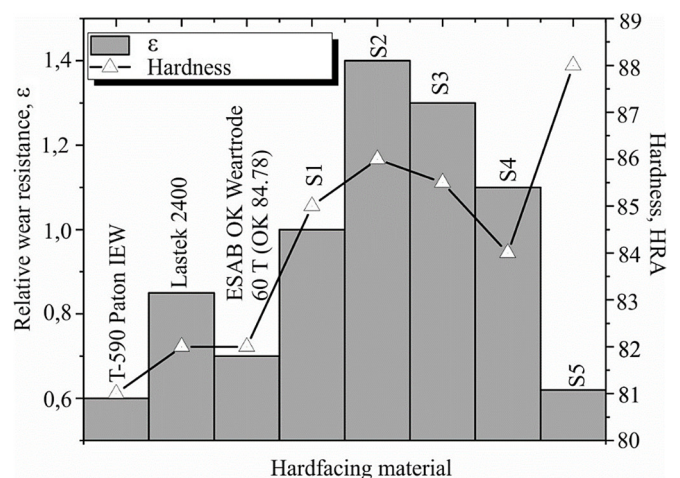


**Fig. 5 Temperature dependences of equilibrium phase amount in Me-B-C systems: Fe-Ti-Mo-B-C specimen 2 (a); Fe-Ti-Cr-B-C specimen 3 (b); Fe-Mo-B-C specimen 4 (c); Fe-Cr-B-C specimen 5 (d)**

It can be seen (Fig. 6) that tested hardfacing obtained by modern serial production electrodes are given in higher wear level, whereas the hardfacing based on Me-B-C system investigated are situated in a lower level of wear rate in conditions of abrasion wear with high specific loads. Hardfacing based on Fe-Cr-B-C shows highest hardness (~ 88 HRA) among other tested hardfacing with the lowest wear resistance. This difference between hardness and wear resistance is the result of influence of coarse structure on wear resistance in such conditions. Thus, in conditions of abrasion wear with high specific loads the main feature that determines wear resistance is features of structure formation, not hardness.

High wear resistance can be observed for hardfacing based on Fe-Ti-B-C and Fe-Mo-B-C systems. These hardfacing due to “*in-situ*” synthesis reaction during FCAW contains of hexagonal-shaped and uniformly distributed

particles in eutectic matrix. Such structures (Fig. 3a, Fig. 4c) works better in such conditions of abrasion wear. Hard facing based on Fe-Ti-Cr-B-C system shows higher wear rate than hardfacing based on Fe-Ti-B-C and Fe-Mo-B-C with hardness lower than hardfacing based on Fe-Cr-B-C system. Such wear resistance is result of fine structure of specimen 3 (Fig. 4b). The highest wear resistance can be observed for hardfacing based on Fe-Ti-Mo-B-C due to fine structure which contains refractory borides and carbides and their solid solutions that forms due to “*in-situ*” synthesis reaction during FCAW, what can be obtained with using powders of pure metal and their combinations as initial reaction mixture for electrodes. Such hard facing are characterized with high hardness (~ 86 HRA) and increased wear resistance in conditions of abrasion wear with high specific and cyclic loads.



**Fig. 6 Dependence of relative wear resistance ε (wear testing with fixed abrasive) and hardness on hardfacing material**

## DISCUSSION

Obtained hardfacing coatings are characterized with higher wear resistance in conditions of abrasion wear with high specific loads compared with tested serial production electrodes. It can be seen that the hardfacing layer produced by Fe-Ti-Mo-B-C hardfacing system shows wear resistance: more than 2 times higher than T-590 Paton IEW electrodes, 2 times higher than ESAB OK Weartrode 60 (OK 84.78) electrodes, and about 1.4 times higher than Lastek 2400 electrodes.

In such conditions the main factor that determines the wear resistance is not the hardness, but the features of structure formation. As shown on the Fig. 6 hardfacing material based on Fe-Cr-B-C system shows the highest hardness (~ 88 HRA) among the tested hardfacings, as well as the wear rate is the highest. This is explained by the fact that structure of S5 are characterized with high amounts of coarse grains structure. The structure of Fe-Ti-Cr-B-C hardfacing shows decreasing of hardness (~ 84 HRA) with increasing of wear resistance, which can be explained by the fact of grain size reduction. The hardfacing based on Fe-Ti-B-C and Fe-Mo-B-C systems shows higher hardness and higher wear resistance than hardfacing based on Fe-Cr-B-C system, which is result of the difference between structure. Fe-Cr-B-C structure consist of coarse dendrites,



while Fe-Ti-B-C and Fe-Mo-B-C consist of metal matrix and hexagonal-shaped borides. It is a result of "in-situ" synthesis, which leads to fine grains structure which contains of refractory borides, carbides and their solid solutions. The "in-situ" synthesis technique can only occur with FCAW while used powders of pure metals as reactional components and not the ferroalloys. The highest wear resistance shown by specimen 2 based on Fe-Ti-Mo-B-C system due to fine structure with metal matrix and solid solutions with increased hardness.

Results of this investigation can be provided for improvement of abrasion resistance of equipment that works in conditions with abrasion wear and high specific and cyclic loads, as well as to regulate the time between overhauls (TBO) periods for such equipment: augers for production of solid fuel briquettes, augers for production of construction ceramics, bricks, etc. Improvement the quality of the management system in production engineering is achieved by using of Ti and Mo powders that is more economical than using of expensive Nb, Co, W powders, and the increasing of TBO period by cheaper restoration of wear parts and prolonging of working time of these parts.

Further complex tests of the developed materials as hardfacing coatings on working elements of equipment and theoretical calculation of phase compositions of hardfacings is desire. Investigations of proposed Fe-Ti-Mo-B-C and Fe-Ti-Cr-B-C systems with not equimolar ratio of Me/Ti and investigations of such systems with different filling coefficient ( $K_f$ ) of the wire can be done. Also, hardfacings based on Fe-Ti-Mo-B-C, Fe-Ti-Cr-B-C, Fe-Mo-B-C and Fe-Cr-B-C systems obtained by using as reaction mixtures powders of pure metals and their combinations need to be investigated with SEM and EDS analysis.

## CONCLUSIONS

The present work showed that using the powders of pure metals leads to "in-situ" synthesis reaction during FCAW, what leads to fine structure which contains of refractory borides and carbides with increased wear resistance in conditions of abrasion wear with high specific and cyclic loads.

Hardfacing coating based on Fe-Ti-Mo-B-C system possess much higher wear resistance than the modern serial production electrodes based on Fe-Cr-C and Fe-Cr-B-C systems and higher wear resistance than materials based on Fe-Ti-B-C, Fe-Mo-B-C systems, with high hardness (~ 85.5 HRA).

Hardfacing material based on Fe-Cr-B-C system showed the highest hardness (~ 88 HRA) among other tested hardfacings but with the much lower wear resistance due to high amounts of coarse grains of  $(Cr, Fe)_2B_3$  in the structure.

The wear resistance in such conditions were affected by features of structure formation, not by hardness.

Using of proposed systems leads to improvement of quality of the management system in production engineering of restoration of equipment parts.

## REFERENCES

- [1] O.O. Ivanov, P.M. Prysyazhnyuk, D.L. Lutsak, M.Y. Burda, L.D. Lutsak, "Increasing the durability of working elements of equipment for abrasive-containing masses processing" *Problems of Tribology*, vol. 24, no. 3/93, pp. 14-21, 2019.
- [2] J.J. Coronado, H.F. Caicedo, A.L. Gomez, "The effects of welding processes on abrasive wear resistance for hardfacing deposits" *Tribology International*, vol. 42, pp. 745-749, 2009.
- [3] M. Roy, Ed. *Surface Engineering for Enhanced Performance against Wear*. Springer, 2013, pp. 152-155.
- [4] F. Sadeghi, N. Hamidreza and A. Alireza, "The effect of Ta substitution for Nb on the microstructure and wear resistance of an Fe-Cr-C hardfacing alloy." *Surface and Coatings Technology*, vol. 324, pp. 85-91, 2017.
- [5] Q. Wang and Li Xiaoyan, "Effects of Nb, V, and W on microstructure and abrasion resistance of Fe-Cr-C hardfacing alloys." *Welding Journal*, vol. 89, no. 6, pp 133-139, 2010.
- [6] V.E. Buchanan, P.H. Shipway and D.G. McCartney, "Microstructure and abrasive wear behaviour of shielded metal arc welding hardfacings used in the sugarcane industry." *Wear*, vol. 263, pp. 99-110, 2007.
- [7] M. Kirchgabner, E. Badisch, F. Franek, "Behaviour of iron-based hardfacing alloys under abrasion and impact" *Wear*, vol. 265, pp. 772-779, 2008.
- [8] D. J. Kotecki and J. S. Ogborn, "Abrasion resistance of iron-based hardfacing alloys." *Welding Journal*, vol. 74, no. 8, pp. 269-278, 1995.
- [9] P. M. Prysyazhnyuk, T. A. Shihab and V. H. Panchuk, "Formation of the Structure of Cr 3 C 2-MNMTs 60-20-20 Cermets." *Materials Science*, vol. 52, no. 2, pp. 188-193, 2016.
- [10] Ya. A. Kryl and P. M. Prysyazhnyuk, "Structure formation and properties of NbC-Hadfield steel cermets." *Journal of Superhard Materials*, vol. 35, no. 5, pp. 292-297, 2013.
- [11] Xin-hong Wang, Fang Han and Shi-yao Qu, "Microstructure of the Fe-based hardfacing layers reinforced by TiC-VC-Mo<sub>2</sub>C particles." *Surface and Coatings Technology*, vol. 202, no. 8, pp. 1502-1509, 2008.
- [12] X. Wang, F. Han, X. Liu, S. Qu and Z. Zou, "Microstructure and wear properties of the Fe-Ti-V-Mo-C hardfacing alloy." *Wear*, vol. 265, no. 5-6, pp. 583-589, 2008.
- [13] E. O. Correa, N. G. Alcantara, D. G. Tecco and R. V. Kumar "Development of an Iron-Based Hardfacing Material Reinforced with Fe-(TiW)C Composite Powder" *Metallurgical and Materials Transactions A*, vol. 38A, pp. 937-945, 2007.
- [14] A. Jilleh et al., "Microstructural and mechanical properties investigation of TiC reinforced hardface alloy deposited on mild steel substrate." *Transactions of the Indian Institute of Metals*, vol. 66, no. 4, pp. 433-436, 2013.
- [15] D. Liu, R. Liu and Y. Wei, "Effects of titanium additive on microstructure and wear performance of iron-based slag-free self-shielded flux-cored wire." *Surface and Coatings Technology*, vol. 207, pp. 579-586, 2012.
- [16] M. Zhang, S.X. Luo, S.S. Liu, X.H. Wang, "Effect of Molybdenum on the Wear Properties of (Ti,Mo)C-TiB<sub>2</sub>-Mo<sub>2</sub>B Particles Reinforced Fe-Based Laser Cladding Composite Coatings" *Journal of Tribology*, vol. 140, no. 5, 2018.
- [17] X. Qi, Z. Jia, Q. Yang, Y. Yang, "Effects of vanadium additive on structure property and tribological performance of high chromium cast iron hardfacing metal" *Surface and Coatings Technology*, vol. 205, pp. 5510-5514, 2011.

- [18] A. L. Borisova. *Sovmestymost tuhoplavkykh soedyneni s metallamy y hrafytom*. Kyev: Nauk. dumka, 1985, pp. 59-60.
- [19] Yu Xi Wang, Sam Zhang, "Toward hard yet tough ceramic coatings" *Surface & Coatings Technology*, vol. 258, pp. 1-16, 2014.
- [20] E.A. Levashov, V.I. Kosayanin, L.M. Krukova, J.J. Moore, D.L. Olson, "Structure and properties of 'Ti-C-B composite thin films produced by sputtering of composite Tic-TiB, targets" *Surface and Coatings Technology*, vol. 92, pp. 34-41, 1997.

---

**Oleksandr Ivanov**

ORCID ID: 0000-0003-4678-7956  
Ivano-Frankivsk National Technical University  
of Oil and Gas  
Institute of Mechanical Engineering  
Karpatska St., 15, 76019 Ivano-Frankivsk, Ukraine  
e-mail: o.ivanov@nung.edu.ua

**Pavlo Prsyazhnyuk**

ORCID ID: 0000-0002-8325-3745  
Ivano-Frankivsk National Technical University  
of Oil and Gas  
Institute of Mechanical Engineering  
Karpatska St., 15, 76019 Ivano-Frankivsk, Ukraine  
e-mail: pavlo1752010@gmail.com

**Dmytro Lutsak**

ORCID ID: 0000-0001-9496-3542  
Ivano-Frankivsk National Technical University  
of Oil and Gas  
Institute of Mechanical Engineering  
Karpatska St., 15, 76019 Ivano-Frankivsk, Ukraine  
e-mail: d.l.lutsak@gmail.com

**Oleh Matvienkiv**

ORCID ID: 0000-0003-1717-5416  
Ivano-Frankivsk National Technical University  
of Oil and Gas  
Institute of Mechanical Engineering  
Karpatska St., 15, 76019 Ivano-Frankivsk, Ukraine  
e-mail: olegmatvienkiv@gmail.com

**Viktor Aulin**

ORCID ID: 0000-0003-2737-120X  
Central Ukrainian National Technical University  
Department of Operation and Machine Repair  
Avenue University, 8, 25006 Kropivnitskiy, Ukraine  
e-mail: aulinvv@gmail.com