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DEVELOPMENT OF NEW ELECTRODE MATERIALS, METHODS OF RESTORATION AND PROTECTION OF THIN-WALLED PARTS OF EQUIPMENT, WHICH ARE OPERATED UNDER THE CONDITIONS OF ABRASIVE AND GAS-ABRASIVE WEAR

M.M. Student, A.A. Voytovych, Ya.Ya. Sirak and **V.M. Gvozdetskyi**
G.V. Karpenko Physical-Mechanical Institute of the NAS of Ukraine
5 Naukova Str., 79060, Lviv, Ukraine. E-mail: pminasu@ipm.lviv.ua

A wide range of parts and equipment of chemical, oil, agricultural, machine-building, transport, energy and other industries are operated under abrasive wear conditions. In Ukraine, electric arc surfacing with flux-cored wires of the Fe–Cr–B–C system is widely used to protect against abrasive wear and restore worn surfaces by surfacing. Such flux-cored wires have a low cost and the deposited metal has a satisfactory wear resistance. However, the main disadvantage of the layers deposited by such flux-cored wires, are dendrites of the first and second order with acicular morphology. Sharp peaks of the solid phase act as stress concentrators, from which after impact the cracking of the deposited metal begins, followed by its chipping. It is known that the formation of rounded reinforcing phases reduces the concentration of stresses in the deposited layer and, as a consequence, increases wear resistance. This paper proposes the dispersion of structural components in the deposited metal by surfacing under the action of mechanical vibration on the deposited metal, which is especially rational to use for manufacture by surfacing of bimetallic wear plates, and for large-sized parts it is proposed to perform a dispersion of structural components in the deposited metal with modifying charge flux-cored wires of Fe–Cr–B–C system by adding PAM-4 powder of aluminium-magnesium master alloy to it. 5 Ref., 2 Tables, 5 Figures.

Keywords: surfacing, bimetallic sheets, wear resistance, boride inclusions

Materials and procedures of investigations. To form the deposited metal, flux-cored wires (FCW) with a diameter of 3.2 mm were used. Their sheath is made of a low-carbon steel 08kp (rimmed), filled with a powder charge based on ferroalloys. For the investigations FCWs were selected, having a ferritic or austenitic matrix in the deposited metal. The chemical composition of FCWs (Table 1) contains a high amount of chromium, boron, which has a positive effect on wear resistance of the deposited metal, as far as in the structure solid boride inclusions are precipitated.

The addition of PAM-4 powder of aluminium-magnesium master alloy to the charge of FCWs during surfacing forms a dispersed magnesium oxide in the welding pool, which affects the dispersion of the structural components, as well as strengthening of the deposited layer.

Procedures of investigations. The metal deposited by FCW was formed using suspension head ABS (power source is generator PSO 500). For protection against atmospheric influence, the flux OSTs 45 was used. The formation of deposited metal from FCWs was performed on a metal substrate of steel St3sp with the size of 150×300 mm in two layers. Vibration treatment [1–5] of the molten metal pool in the zone of electric arc burning was carried out under the following modes: oscillation frequency is 100 Hz, amplitude is 0, 70, 300 μm at a horizontal vibration. Microstructure of the deposited layers was studied on a transverse microsection using an electron microscope EVO 40 XVP. Hardness measurements were performed in a PMT-3 microhardness tester with a batch weight of 200 g. The wear resistance of deposited layers was investigated under different wear

Table 1. Chemical composition of the charge of the used flux-cored wires, wt.%

Grade of FCW	C	B	Cr	Ti	Mn	Al	Mg	Si	Fe
Kh10R3G2S (ferritic matrix)	0.08	3.5	10.0	–	2.0	–	–	1.0	Balance
80Kh20R3T (austenitic matrix)	0.8	3.0	20.0	1.0	–	–	–		
80Kh20R3T + 1 % of PAM (austenitic matrix)	0.8	3.0	20.0	1.0	–	1.0	0.3		

M.M. Student — https://orcid.org/0000-0002-5992-5898, Ya.Ya. Sirak — https://orcid.org/0000-0001-8748-8456

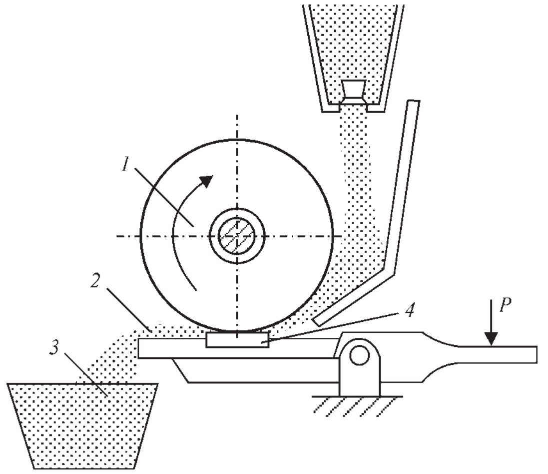

Figure 1. Scheme of installation for investigation of abrasive wear by an unfixed abrasive: *1* — rubber disc; *2* — sand; *3* — reservoir for collecting abrasive; *4* — specimen

conditions. Abrasive wear with an unfixed abrasive was evaluated according to GOST 23.208–79 (Figure 1). A dried high-silica sand with the particles size of 200–1000 μm was continuously supplied to the contact area of the rubber disc and the specimen. The speed of the disc rotation was 25 m/s, and the force of its pressing to the specimen was 2.4 kN.

To evaluate the wear of the fixed abrasive (Figure 2) an abrasive disc SM-2 on a ceramic bond was used. The linear friction speed was 0.4 m/s, the load in the area of a linear contact was 1.5 kN.

Impact wear (Figure 3) was evaluated at an impact force of 12 kJ applied by a ball with a diameter of 25 mm of steel ShKh 15, which fell on the test surface at a frequency of 40 s^{-1}. The duration of the experiment was 3600 s. The weight loss of the specimens was determined by electronic balance with the accuracy of $2 \cdot 10^{-4}$ g.

Structure of deposited metal. Phase analysis showed that the metal deposited by FCW Kh10R3G2S without vibration, consists of a ferritic matrix alloyed with chromium and boride inclusions (FeCr)B, $(FeCr)_2B$. It is known from the literature

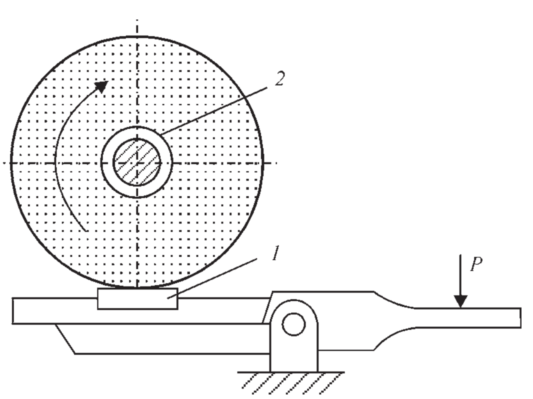

Figure 2. Scheme of installation for investigation of wear of specimens by a rigidly fixed abrasive: *1* — specimen; *2* — abrasive disc

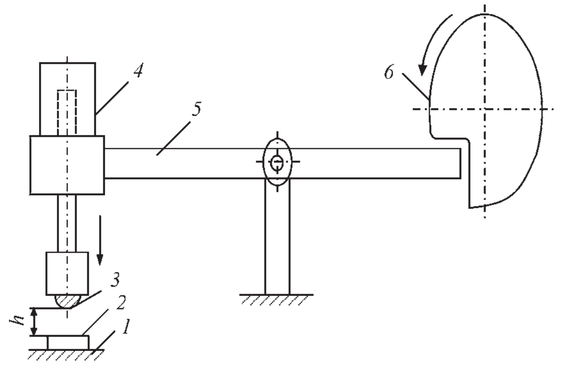

Figure 3. Scheme of installation for investigation of impact wear of specimens: *1* — base; *2* — specimen; *3* — indenter; *4* — batch weight; *5* — balance arm; *6* — eccentric; *h* — distance from the specimen is 10 mm

that the phase $(FeCr)_2B$ contains a lower quantity of chromium and boron than the phase (FeCr)B and is characterized by a lower hardness, but a much higher ductility. Location of inclusions (FeCr)B, $(FeCr)_2B$ in the structure of the deposited metal was identified by microspectral analysis on the sections. It was found that the inclusions of borides of the type (FeCr)B are larger and darker and borides of the type $(FeCr)_2B$ are much smaller and lighter (Figure 4).

In the initial metal from FCW Kh10R3G2S the average size of boride inclusions (FeCr)B, $(FeCr)_2B$ in the structure on the crest of the beads varied from 20 to 75 μm, and in the zone of their overlapping it varied from 50 to 150 μm. At a horizontal vibration with an amplitude of 300 μm, the average size of borides (FeCr)B, $(FeCr)_2B$ decreased to 5–10 μm. The obtained results give grounds to assume that the horizontal vibration significantly disperses structural components of the metal deposited by FCW Kh10R3G2S. This was also checked on the structure of the metal deposited by FCW 80Kh20R3T at the amplitude of oscillations of the substrate of 70, 200 and 300 μm. It was found that also in this case the structural components of the deposited metal (boride inclusions) were significantly grounded with an increase in the oscillation amplitude during surfacing. In particular, boride inclusions (FeCr)B, $(FeCr)_2B$ were maximum grounded by oscillations with an amplitude of 300 μm. The average size of the inclusions was 1–5 μm. Surfacing with the use of vibration of large-sized parts of a complex shape is significantly complicated or becomes impossible. In this case, it was proposed to influence the microstructure of the deposited metal by adding of up to 2 wt.% of PAM-4 powder to the charge of FCW 80Kh20R3T. Due to that, it creates the prerequisites for oxidation of magnesium located in the cavities of the FCW charge with the formation of dispersed particles of magnesium oxide, which become the centres of crystallization and growth of amount of grains from the melt of the deposited metal.

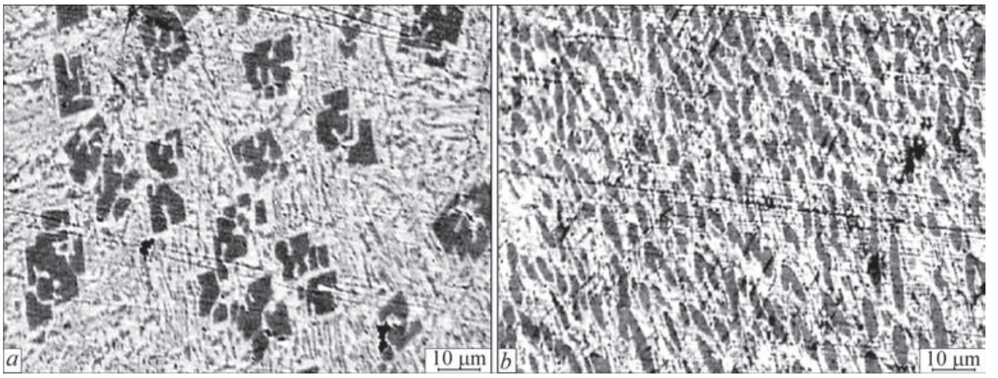

Figure 4. Microstructure on the crests of metal beads, deposited by FCW Kh10R3G2S: *a* — without the vibration; *b* — with the vibration of 300 µm amplitude

In the metal deposited by FCW 80Kh20R3T without adding PAM, acicular large (FeCr)B and small $(FeCr)_2B$ borides are located on the background of the austenitic matrix. The microstructure of the metal deposited by FCW 80Kh20R3T of the base composition and with the addition of PAM powder to the charge was compared and it was found that magnesium alloying contributes to grinding of borides and their globalization.

Spectral and phase analyzes showed that with the addition of PAM powder to the FCW charge, in the microstructure of the deposited metal borides of the type $(FeCr)_2B$ predominated. In the metal deposited by FCW 80Kh20R3T of the base composition, the size of borides was 30–120 µm, and in the metal deposited by FCW with the addition of PAM-4 powder their diameter decreased on the average by 8 times.

Wear resistance of deposited layers. It was established that the layers deposited under the conditions of mechanical vibration have an increased abrasive wear resistance. In particular, the abrasive wear resistance of the layer deposited by the fixed abrasive increased by 2.5 times, and by unfixed one by 2.3 times and under the conditions of a cyclic impact load by 2.8 times. An increase in wear resistance of the layers deposited under the conditions of mechanical vibration is predetermined by a significant reduction in the size of the dispersed reinforcing phases (borides) and a change in their phase composition. In particular, as the average size of boride inclusions decreased from 75 to 5 µm, its microhardness increased from *HV* 700 to *HV* 9300. As the content of the phase $(FeCr)_2B$ in the deposited layer increased, the Young's modulus and resistance to brittle fracture increased, which also affected the improvement of wear resistance of the deposited layer (Table 2).

The application of oscillation during surfacing of the metal by FCW 80Kh20R3T, as well as for the metal deposited by FCW Kh10R3G2S, also leads to a significant decrease in the average size of boride inclusions and, as a consequence, its wear resistance grows. In particular, with a decrease in the average size of boride inclusions from 70 to 5 µm under the conditions of wear by fixed and unfixed abrasive, the wear resistance of the deposited metal increases by 1.7 times, and during wear under the action of cyclic impact loads it grows twice.

Addition of 1 wt.% of PAM-4 to the charge of FCW 80Kh20R3T facilitates an increase in the wear resistance of the deposited metal by 1.6 times under the conditions of wear by fixed and unfixed abrasive; during wear under the action of cyclic impact loads, the wear resistance 1.8 times increased as compared to the metal deposited by FCW of the base composition. This improvement is predetermined by an increase in the hardness of the deposited layer both due to the dispersion of the reinforcing boride phase, as well as due to the additional precipitation of finely dispersed complex-alloyed nitrides in the structure of the deposited layer.

As an example of applying the process of surfacing by FCW, the works were carried out to restore the mill fan VM 100/1200 for the Burstyn TPP. In the system of dust preparation of boiler stations operating on solid fuel, the important components were mill fans. They perform pneumatic transportation of coal dust (with the fraction lower than 100 µm) at a temperature higher than 320 K from the cyclones to the dust feeders and further to the furnace of steam generators.

Table 2. Relative wear resistance of deposited metal with FCW Kh10R3G2S under the conditions of abrasive wear in relation to the deposited metal without the oscillation

Surfacing conditions	Without vibration	Horizontal vibration	
Amplitude of mechanical oscillations, µm	–	70	300
Average size of borides, µm	75	10	5
By fixed abrasive	1	1.4	2.5
By unfixed abrasive	1	1.5	2.3
Under impact loads	1	2.4	2.8
Ratio of phases $(FeCr)B/(FeCr)_2B$	4/1	2.5/4	1/5

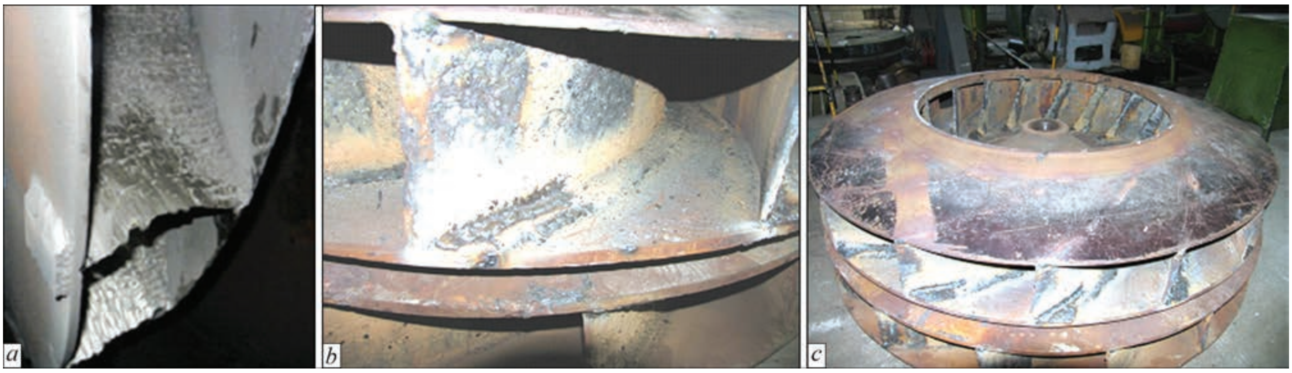

Figure 5. Worn (*a*) and deposited (*b*) wheel blade of the mill fan, renovated wheels of the mill fan VM 100/1200 (*c*)

Therefore, during the operation of the described elements of boiler stations, an intense and nonuniform wear of their working blades, discs and walls of the chambers is observed. Nonuniform wear of the blades leads to a decrease in the power of fans and smoke extractors, unbalancing of rotors, contributes to the vibration of bearings, and, ultimately, destroys bearing units. The time of a continuous operation of smoke extractors in some cases is only 2–3 weeks.

Manufacture of a new mill wheel requires much more costs than surfacing of protective coatings. The main method to continue the operation of the mill wheel is its repair or replacement. Repair is offered to restore the geometric dimensions.

The main method of deposition a protective coating is semi-automatic surfacing. This surfacing allows applying the coating even in hard-to-reach places. For repair and strengthening of the mill fan VM 100/1200, FCW 80Kh20R3TMg was used, which was developed on the basis of FCW 80Kh20R3T with the addition of 1 wt.% of PAM-4 aluminium-magnesium master alloy to the charge (Figure 5).

Experimental and industrial inspection of the operation of mill fans, protected by a deposited layer of the wire PP-Np-80Kh20R3T, modified by the aluminium-magnesium master alloy, carried out at the Burshtyn TPP by the Institute of Physics and Mechanics jointly with the SE «Lviv Design Bureau» showed, that the service life of the strengthened impellers of the fans VM 100/1200 increased by 2.5 times.

Conclusions

1. It was established that vibration of a part during its surfacing causes dispersion of the structure of the deposited metal, as a result of which the average size of separate boride inclusions decreases from 50–150 to 5–10 μm.

2. Mechanical vibration promotes redistribution of the phases during surfacing, as a result of which the microhardness of the deposited metal increases from *HV* 600 to *HV* 870 and is more uniformly distributed on the surface of the deposited metal. The deposited layers produced at a horizontal vibration showed an increased (2.3–2.5 times) abrasion wear resistance at the friction by a fixed and unfixed abrasive as compared to the layer deposited without the vibration.

3. It was established that vibration during surfacing layers increases (1.8 times) their stability at a cyclic impact load. The main factor influencing the impact wear of the deposited metal is its ability to plastically deform and, accordingly, to relax the stresses.

4. It was found that the addition of PAM-4 powder (up to 1 wt.%) to the FCW charge of the Fe–Cr–B–C base system promotes grinding of boride inclusions in the deposited metal (up to 7 times) and 1.6–1.8 times increase in the resistance to abrasive wear.

1. Kuskov, Y.M., Zhdanov, V.A., Ryabtsev, I.O. et al. (2020) Methods for increasing the corrosion resistance of coatings deposited under a flux layer from high-chromium powder wires. *Materials Sci.*, 55(**5**), 710–715.
2. Student, M., Vojtovych, A., Pokhmurska, H. et al. (2019) Mechanical characteristics and wear resistance of the cladding layers obtained by melting of cored wires with simultaneous vibration of substrate. *Strojnicky Casopis*, 69(**1**), 109–122.
3. Pokhmurs'ka, H.V., Student, M.M., Lanets', O.S., Voitovych, A.A. (2015) Influence of vibration in the course of surfacing of a protective layer on its microstructure and impact-abrasive wear. *Materials Sci.*, 51(**3**), 412–417.
4. Voitovych, A.A., Pokhmurs'ka, H.V., Student, M.M., Student, O.Z. (2016) Microstructure and abrasive-wear resistance of the vibration-deposited metal of core wires of the basic Fe–Cr–B system. *Ibid*, 52(**3**), 365–370.
5. Pokhmurs'ka, H.V., Student, M.M., Dzyubyk, A.R. et al. (2017) Corrosion resistance of the metal vibration deposited from flux-cored wires based on the Fe–Cr–B system. *Ibid.*, 52(**5**), 694–699.

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