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STUDIES OF COATINGS PRODUCED BY HIGH-VELOCITY OXY-FUEL SPRAYING USING CERMET POWDER BASED ON FeMoNiCrB AMORPHIZING ALLOY

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ABSTRACT

The process of producing composite powders based on amorphizing Fe-alloy with the additives of refractory compounds by the method of high-velocity oxy-fuel spraying was investigated. For spraying composite powders FeMoNiCrB–(Ti, Cr)C, FeMoNiCrB–ZrB_2 were used, produced from a mixture of powders of the compositions by mechanical alloying in a planetary mill. As a result of spraying, dense coatings (porosity is less than 3 %) were produced, which were formed from partially deformed particles with a multiphase structure and a uniform distribution of structural components. The results of X-ray diffraction phase analysis indicate the formation of amorphous-crystalline structure in the produced composite coatings. On the X-ray patterns, the maximum peak amplitude from the crystalline phase against the background of the amorphous halo corresponds to the TiCN phase in the coating FeMoNiCrB–(Ti, Cr)C and the ZrB_2 phase in the FeMoNiCrB–ZrB coating. The size of the measured microhardness for the composite coating FeMoNiCrB–(Ti, Cr)C amounts to — 5.5±0.25 GPa, and for the coating FeMoNiCrB–ZrB_2 it is 5.9±0.29 GPa.

KEY WORDS: high-velocity oxy-fuel spraying, amorphous phase, amorphous iron-based alloy, composite powder, composite coating, microstructure, microhardness

INTRODUCTION

Amorphous metallic iron-based materials are widely used in industry due to their advantages, such as high strength and hardness, excellent corrosion and wear resistance, good magnetic properties, as well as relatively low cost of material [1–3]. However, a disadvantage of amorphous compact materials is their low ductility and excessive brittleness at room temperature, as well as low efficiency of equipment and high production costs, which significantly limits their practical application as structural materials [4]. To eliminate these disadvantages, materials based on amorphous alloys are used on the surface of products in the form of protective coatings, which are produced by thermal spraying. The basis for the scientific and practical interest of the use of amorphous iron-based coatings and amorphous composite coatings in order to increase the stability of the surface of products is the cooling rate in thermal spraying of the powder melt particles, which is 10^5–10^6 K/s and is sufficient for amorphization of the coating material. In addition, amorphous metal coatings can be applied on large-sized and complex parts. This allows expanding the scope of their practical application.

For deposition of coatings from amorphizing iron-based alloys, the methods of plasma, detonation, electric arc and high-velocity oxy-fuel (HVOF, HVAF) spraying are used. The produced coatings are used to increase the corrosion stability of containers for storage and transportation of spent nuclear fuel as an alternative replacement of expensive nickel and titanium alloys [5]; on parts operating in the conditions of corrosion, corrosion-erosion and abrasive wear for replacement of galvanic chrome plating [6, 7]; on parts of mobile warehouses [8]; to strengthen and restore the pipes of industrial boilers, operating in the conditions of high-temperature erosion wear [9]. The process of HVOF spraying is most widely used to produce coatings with an amorphous structure due to the use of a relatively low temperature and high jet velocity in this method, which results in the formation of a coating with a high density and adhesion strength with the base.

Along with the use of iron-based alloys, composite coatings with an amorphous matrix are developed, which was strengthened by the second phase. As reinforcing additives, TiN nitrides, B_4C and WC carbides, CrB_2 borides, Al_2O_3 oxides, as well as stainless steel, NiCr, etc. are used [10–14]. These composite coatings show a significant increase in hardness, wear resistance and corrosion resistance as compared to the basic analogue.

In this paper, a study of the structure formation and phase composition of composite coatings, produced by HVOF based on Fe-alloy, which is amorphised, with reinforcing additives of refractory compounds (Ti, Cr)C, $ZrBr_2$, was carried out.

Table 1. Characteristics of powders for oxy-fuel spraying of coatings

Composition, wt.%	Particle size, μm	Method of producing
FeMoNiCrB (36.2Fe–29.9Mo–23.6Ni–7.6Cr–2.7B)	<40	Spraying of melt by nitrogen
77 FeMoNiCrB–23 (Ti, Cr)C	<40	MA in PM 1.5 h
75 FeMoNiCrB–25 ZrB_2	<80	

MATERIALS AND PROCEDURES OF INVESTIGATIONS

For HVOF coatings with an amorphous structure, powders based on amorphous alloy FeMoNiCrB were used, produced by mechanical alloying (MA) in a planetary mill (PM) [15]. The characteristics of powders are shown in Table 1.

The spraying was performed in the installation (HVOF) UVShGPN-M1 on the following technological parameters of the process: propane-butane pressure is 4 atm, oxygen pressure is 7 atm, air pressure is 6 atm, nitrogen pressure is 5 atm, spraying distance is 120 mm. The coatings FeMoNiCrB–(Ti, Cr)C and FeMoNiCrB–ZrB_2 were deposited to the substrate NiCr (thickness is 50–100 μm), which was sprayed by electric arc method (wire diameter is 2 mm).

In metallographic examinations, an optical microscope Neophot-32 with a digital photography device was used; measurement of microhardness was carried out in a PMT-3 device. X-ray diffraction analysis (XRD) of coatings was carried out in the installation DRON-UM-1, CuK_α radiation, monochromatic.

RESULTS OF INVESTIGATIONS

Metallographic analysis revealed that coatings produced from all the studied materials have a dense,

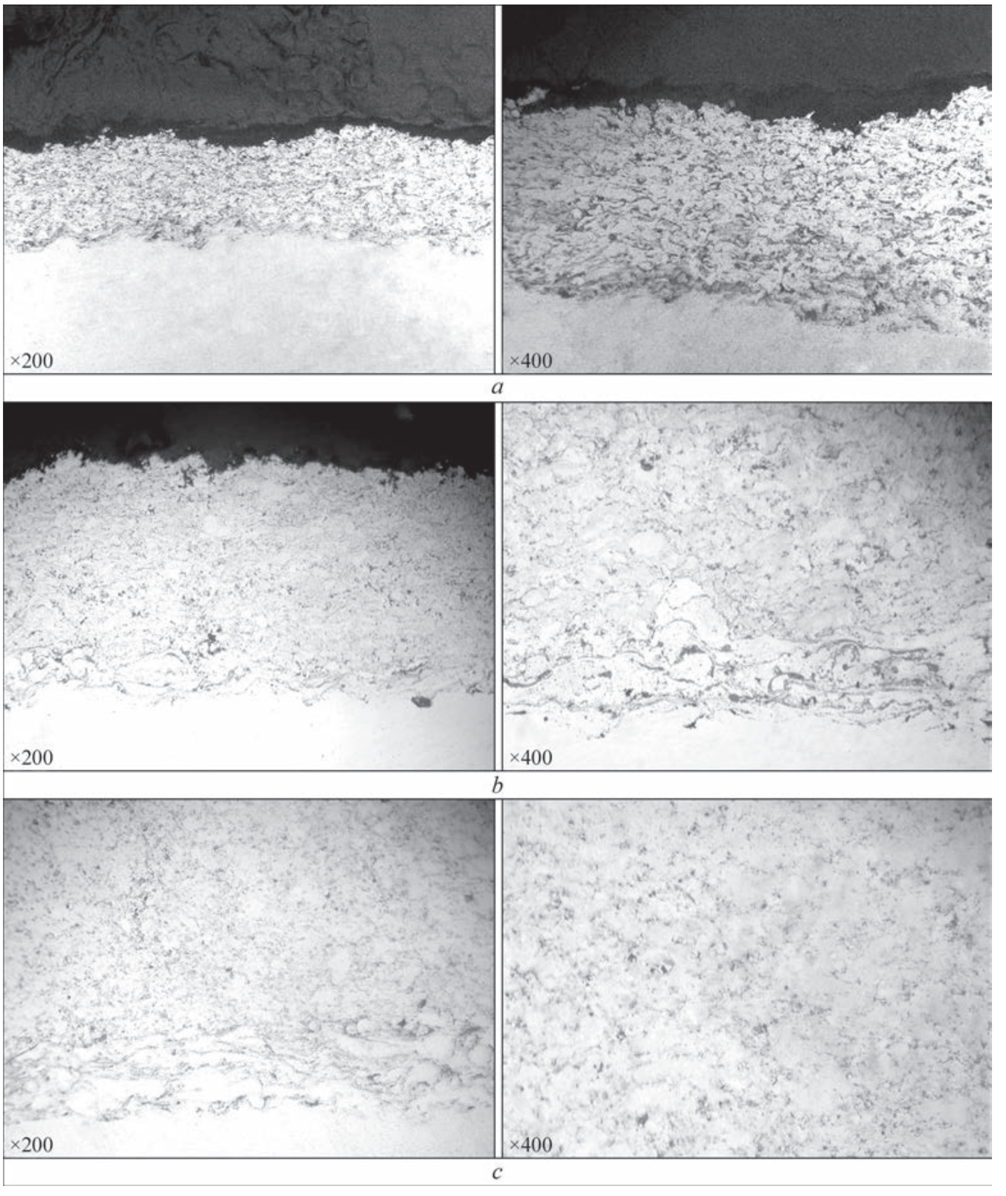

Figure 1. Microstructure of HVOF-coatings: *a* — FeMoNiCrB; *b* — FeMoNiCrB–(Ti, Cr)C; *c* — FeMoNiCrB–ZrB_2

Table 2. Results of investigations of HVOF-coatings based on FeMoNiCrB

Coating material	Thickness, μm	Microhardness $HV_{0.05}$, MPa	Phase composition
FeMoNiCrB	200–250	4390±290	AΦ; Mo_2FeB_2; Fe_2B; FeCr; Fe_3O_4; Cr_7Ni_3
FeMoNiCrB–(Ti, Cr)C	300–350	5510±250	AΦ; Fe_2Ti; Cr_7Ni_3; $TiC_{0.3}N_{0.7}$; $TiC_{0.2}N_{0.8}$; $Fe_{15.1}C$; Ni_3Fe; phases in small quantities: Ni_3C; MoC; $FeMoO_4$; FeO; FeC_8
FeMoNiCrB–ZrB_2	900–950	5880±290	AΦ; ZrB_2; Fe; (Fe, Ni) solid solution; Cr_7Ni_3; $MoNi_4$; Ni_2Zr; phases in small quantities: ZrO_2; Fe_2B; Ni_2B; MoB_2; FeO; $Ni_{0.4}Fe_{2.6}O_4$

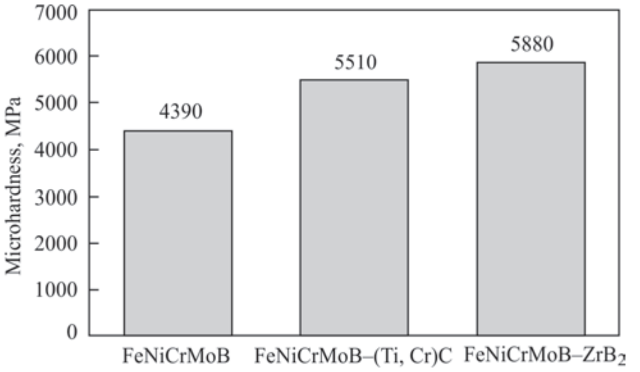

Figure 2. Microhardness of coatings with an amorphised structure produced by the method of HVOF-spraying

fine-grained structure, homogeneous over the whole structure area, which is formed from partially deformed spherical particles (Figure 1). Porosity of the coatings does not exceed 3 vol.%; the coatings FeMoNiCrB–(Ti, Cr)C and FeMoNiCrB–ZrB_2 tightly adhere to the nichrome sublayer and the coating FeMoNiCrB — to the steel base.

Measurement of microhardness of HVOF coatings (Figure 2) showed that the use of reinforcing additives (Ti, Cr)C and ZrB_2 leads to an increase in microhardness of composite coatings by 1120 and 1490 MPa as compared to the coating of the initial FeMoNiCrB powder.

X-ray diffraction analysis revealed (Figure 3) that in the investigated HVOF-coatings, the amorphous phase (APh) is present.

Data from XRD indicate that as a result of HVOF-spraying of powders based on FeMoNiCrB alloy, multiphase coatings were produced, having an amorphous crystalline structure. All the coatings have additional crystalline peaks against the background of halo from the amorphous phase. On X-ray patterns, the maximum peak on the amplitude from the crystalline phase against the background of the amorphous halo corresponds to the phases of Fe_2B and FeCr in the coating FeMoNiCrB; $TiC_{0.3}N_{0.7}$ in the coating FeMoNiCrB–(Ti, Cr)C and the phase ZrB_2, in the coating FeMoNiCrB–ZrB_2. In all the coatings, the intermetallide phase $Cr_7Ni_3$was recorded, having a tetragonal crystalline structure. Iron, as the main element of the initial alloy, is presented in the coatings in the form of oxides (Fe_3O_4, FeO, $FeMoO_4$,$Ni_{0.4}Fe_{2.6}O_4$), borides (Mo_2FeB_2, Fe_2B), intermetallides (FeCr, Fe_2Ti, Ni_3Fe), carbides ($Fe_{15.1}C$, FeC_8) and (Fe, Ni)-solid solution. In the coating FeMoNiCrB–$ZrB_{2,}$ iron in a pure form was also revealed.

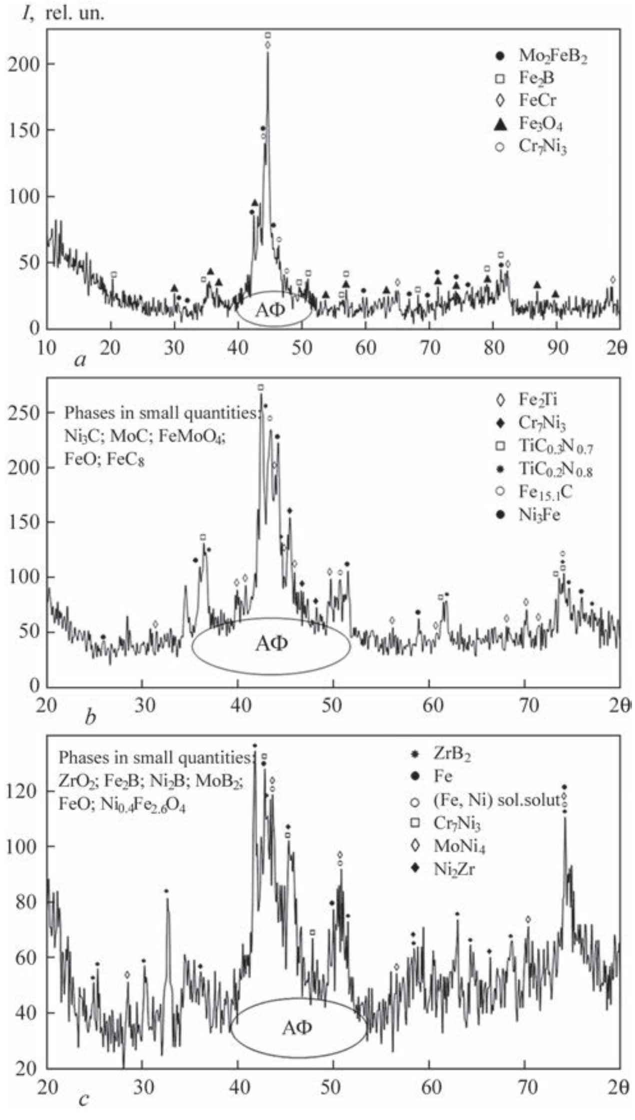

Figure 3. X-ray patterns of HVOF-coatings: *a* — FeMoNiCrB; *b* — FeMoNiCrB–(Ti, Cr)C; *c* — FeMoNiCrB–ZrB_2

The obtained results of the study of HVOF-coatings based on the FeMoNiCrB alloy are shown in Table 2.

CONCLUSIONS

Applying the method of high-velocity oxy-fuel spraying using composite powders produced by mechanical alloying based on Fe-alloy that is amorphised, the coatings FeMoNiCrB–(Ti, Cr)C and FeMoNiCrB–ZrB_2 with an amorphous crystalline structure were produced.

The produced coatings are characterized by a uniform distribution of structural components, have a structure, that is homogeneous over the entire area, which is formed from partially deformed spherical particles. The porosity of coatings does not exceed 3 %.

It was revealed that the presence of reinforcing components (Ti, Cr)C, ZrB_2 leads to an increase in microhardness of coatings as compared to the coating of the initial FeMoNiCrB powder by 1120 and 1490 MPa, respectively.

REFERENCES

1. Kim, S.W., Namkung, J., Kwon, O. (2012) Manufacture and industrial application of Fe-based metallic glasses. *Mat. Sci. Forum*, **706–709**, 1324–1330. DOI: https://doi.org/10.4028/www.scientific.net/msf.706-709.1324
2. Yuting, D., Guofeng, M. (2020) Research progress of Fe-based amorphous/nanocrystalline alloys. In: *IOP Conf. Series: Earth and Environmental Science*, **565**, 012048. DOI: https://doi.org/10.1088/1755-1315/565/1/012048
3. Li, H.X., Lu, Z.C., Wang, S.L. et al. (2019) Fe-based bulk metallic glasses: Glass formation, fabrication, properties and applications. *Progress in Mater. Sci.*, **103**, 235–318. DOI: https://doi.org/10.1016/j.pmatsci.2019.01.003
4. Guo, S.F., Liu, L., Li, N., Li, Y. (2010) Fe-based bulk metallic glass matrix composite with large plasticity. *Scripta Materialia*, 62(**6**), 329–332. DOI: https://doi.org/10.1016/j.scriptamat.2009.10.024
5. Blink, J., Farmer, J., Choi, J., Saw, C. (2009) Applications in the nuclear industry for thermal spray amorphous metal and ceramic coatings. *Metallurgical and Materials Transact. A*, **40**, 1344–1354. DOI: https://doi.org/10.1007/s11661-009-9830-4
6. Branagan, D.J. et al. (2006) Wear and corrosion resistant amorphous/nanostructured steel coatings for replacement of electrolytic hard chromium, ITSC. Ed. by B. Marple. In: *Proc. of the 2006 ITSC, ASM Intern., Materials Park, OH.*
7. Lu, W., Wu, Y., Zhang, J. et al. (2010) Microstructure and corrosion resistance of plasma sprayed Fe-based alloy coating as an alternative to hard chromium. *J. of Thermal Spray Technology*, 20(**5**), 1063–1070. DOI: https://doi.org/10.1007/s11666-010-9611-z
8. Artemchuk, V.V., Astakhov, E.A. (2012) Structure and properties of amorphous renewable iron-based coatings. Visnyk NTU KhPI. *Series: New Solutions in Modern Technologies*, **26**, 10–15 [in Ukrainian].
9. Cheng, J.B., Liang, X.B., Chen, Y.X. et al. (2012) High-temperature erosion resistance of FeBSiNb amorphous coatings deposited by arc spraying for boiler applications. *J. of Thermal Spray Technology*, 22(**5**), 820–827. DOI: https://doi.org/10.1007/s11666-012-9876-5
10. Yugeswaran, S., Kobayashi, A., Suresh, K., Subramanian, B. (2013) Characterization of gas tunnel type plasma sprayed TiN reinforced Fe-based metallic glass coatings. *J. of Alloys and Compounds*, **551**, 168–175. DOI: https://doi.org/10.1016/j.jallcom.2012.09.111.
11. Yoon, S., Kim, J., Kim, B.D., Lee, C. (2010) Tribological behavior of B_4C reinforced Fe-base bulk metallic glass composite coating. *Surface and Coatings Technology*, 205(**7**), 1962–1968. DOI: https://doi.org/10.1016/j.surfcoat.2010.08.07
12. Yasir, M., Zhang, C., Wang, W. et al. (2015) Wear behaviors of Fe-based amorphous composite coatings reinforced by Al_2O_3 particles in air and in NaCl solution. *Materials & Design*, **88**, 207–213. DOI: https://doi.org/10.1016/j.matdes.2015.08.142
13. Lampke, T., Wielage, B., Pokhmurska, H. et al. (2011) Development of particle-reinforced nanostructured iron-based composite alloys for thermal spraying. *Surface and Coatings Technology*, 205(**12**), 3671–3676. DOI: https://doi.org/10.1016/j.surfcoat.2011.01.00
14. Wang, S., Cheng, J., Yi, S.-H., Ke, L. (2014) Corrosion resistance of Fe-based amorphous metallic matrix coating fabricated by HVOF thermal spraying. *Transact. of Nonferrous Metals Society of China*, 24(**1**), 146–151. DOI: https://doi.org/10.1016/s1003-6326(14)63040-5
15. Borysov, Yu.S., Borysova, A.L., Burlachenko, O.M. et al. (2021) Composite powders based on FeMoNiCrB amorphizing alloy with additives of refractory compounds for thermal spraying of coatings. *The Paton Welding J.*, **11**, 38–47. DOI: https://doi.org/10.37434/tpwj2021.11.07

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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