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DEFORMATION-ACTIVATED MARTENSITIC TRANSFORMATION IN COATINGS OBTAINED BY HYPERSONIC METALLISATION OF HIGH-CHROMIUM STEELS

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Abstract: The structural-phase state and wear resistance of coatings from high-chromium AISI 420 and A756 steels obtained by hypersonic metallisation (HM) were studied. It has been shown that coatings from martensitic steels after deposition contain an increased amount of metastable austenitic phase. In particular, 15 vol.% γ-faze is registered in a AISI 420 steel coating, and 70 vol.% γ-faze in a A756 steel coating. It has been established that during friction of hypersonic metallisation coatings of high-chromium steels, deformation-activated γ→α transformation in their surface layers leads to a significant increase in microhardness and the wear resistance of coatings.

Keywords: hypersonic metallisation, high-chromium steel, metastable austenitic phase, deformation-activated γ→α transformation, wear resistance.

1. INTRODUCTION

The use of hypersonic metallisation for getting steel coatings to restore worn friction surfaces is a promising method for efficiently forming metal layers with the required set of properties on the surfaces of parts. The method of hypersonic metallisation is characterised by high productivity, economy and satisfactory physical and mechanical properties of the resulting coatings [Belotserkovsky, Priadko and Cherepko 1997; Belotserkovsky 2014]. However, the properties of sprayed coatings are often inferior to monolithic materials. In particular, the wear resistance of hypersonic metallisation coatings is significantly lower than the wear resistance of monolithic steels [Belyi and Kukareko 2007a,b]. To obtain hypersonic metallisation coatings with relatively high wear resistance, it is advisable to use alloyed martensitic steels when spraying. It was shown in the works [Kukareko et al. 2013; 2015] that HM-coatings made of high-chromium steels are characterised by increased wear resistance and hardness. At the same time, the nature of the high wear resistance of HM coatings of high-chromium martensitic steels is not well understood.

In this regard, the aim of the work was to study the structure and tribological properties of hypersonic metallisation coatings of AISI 420 and A756 steel under conditions of tight adhesive interaction and to establish the laws describing the formation of wear-resistant layers on the coating surface.

2. OBTAINING SAMPLES AND RESEARCH METHODS

Coatings of AISI 420 and A756 wire steels (Tab. 1), sprayed by hypersonic metallisation [Belotserkovsky 2014] on plates from 1035 steel, were researched. The coatings were sprayed using hypersonic metallisation using the ADM-10 unit [Belotserkovsky 2014]. In this case, products of gas combustion heated to a temperature of 2,000–3,000 K, flowing through the Laval nozzle, acquire a speed of 900–1,100 m/s, which makes it possible to accelerate the particles of the sprayed material to speeds of an order of 500 m/s and form coatings with increased adhesion strength to the substrate than with conventional electro-metallisation. The coatings were sprayed according to the following parameters: air pressure 0.35 MPa, propane-butane mixture pressure 0.37 MPa, current source voltage 30–32 V, current strength 195 A. The size of the sprayed particles was from 5 to 40 microns. The particle size was determined by spraying the particles into a container with water, followed by their measurement. For research, samples (size 8×6×5 mm) were cut from coated plates.

Table 1. Chemical composition of wire steels

Wire steel	**Element concentration, wt. %**						
	C	Cr	Ni	Ti	Mn	Si	Fe
AISI 420	0.42	13.20	0.40	—	0.35	0.40	Base
A756	0.96	18.50	0.60	0.20	0.80	0.80	Base

Metallographic studies of HM coatings were carried out on an ALTAMI MET 1MT optical microscope. The phase composition of HM coatings was studied using a DRON-3.0 diffractometer in monochromatised cobalt radiation (CoK_{α}) at a voltage of 28 kV and an anode current of 14 mA. X-ray decoding was carried out using Crystallographica Search-Match software with a PDF-2 card index.

Comparative tribological tests were carried out in dry friction mode. The tests were carried out according to the scheme of the reciprocating motion of a prismatic sample (8×6×5 mm) along a plate counterbody at an average speed of mutual displacement ≈ 0.1 m/s. A plate (90×30×3 mm) made of hardened N8 carbon steel with a hardness of 700 ±17 HV 10 was used as a counterbody (no abrasive particles).

The nominal specific load of tests P under dry friction was 1.5 MPa. The friction path L was ≈ 1200 m, with intermediate measurements of mass wear.

Vickers hardness and microhardness were measured on a DuraScan 20 hardness tester with an indenter load of 10 kg (98 N), 25 g (0.24 N).

3. RESEARCH RESULTS AND DISCUSSION

The sprayed coatings had a thickness of ≈ 06–08 mm. As a result of spraying, coatings are formed containing alternating layers of metal and oxides (Fig. 1). The porosity of the sprayed coatings did not exceed 5 vol.%.

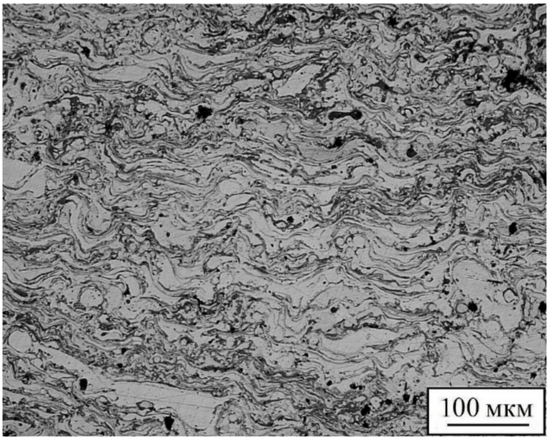

Fig. 1. Characteristic microstructure of a hypersonic metallisation coating of AISI 420 steel

The phase composition of the HM coating of AISI 420 steel after mechanical grinding included: α-Fe (55 vol.%), austenite γ-Fe (15 vol.%), oxides Fe_3O_4 and FeO (26 vol.%). The HM coating from A756 steel had the following phase composition: α-Fe (7 vol.%), γ-Fe (70 vol.%), oxides Fe_3O_4 and FeO (25 vol.%). From the data on the phase composition of HM coatings from martensitic AISI 420 and A756 steels, it can be seen that they contain an increased amount of austenitic phase. High residual austenite content in HM coatings is associated with the cooling features of sprayed coatings. In particular, this is due to isothermal exposure of the coating in the range of bainitic and martensitic transformations (at a temperature of 250–300°C) during metallisation [Kukareko et al. 2017]. It is known that isothermal holding at bainitic transformation temperatures stabilises the austenitic phase [Novikov 1986]. Subsequent delayed cooling of HM coatings in the range of martensitic transformation leads to the preservation of an increased amount of γ-phase in the coatings of martensitic steels [Kukareko, Belotserkovsky and Grigorchik 2015; Kukareko et al. 2017].

In addition, it should be noted that the polished coating of A756 steel contains an abnormally high amount of γ-phase compared to the coating of AISI 420 steel. This is due to greater thermal stabilisation of austenite due to the increased carbon content in the sprayed A756 steel. As a result, the sprayed coating of AISI 420 steel has a relatively higher value of the hardness of the surface layer (600 ±15 HV 10), while the hardness of the coating of 95X18 steel, having a predominantly austenitic structure, is 350 ±10 HV 10 (Tab. 2).

The results of tribotechnical testing of HM coatings of high-chromium steels are presented in Table 2 and Figure 2.

Table 2. Microhardness, austenite content and the intensity of mass wear of hypersonic metallisation coatings of high-chromium steels

Coating material	Hardness, HV 10	Intensity of mass wear under conditions of dry friction I_q,·10^{-3}, mg/m	Austenite content in the surface layers of the coatings after spraying $V_γ$, vol.%	Austenite content in the surface layers of coatings after friction $V_γ$, vol.%	Microhardness of the coating after friction, HV 0.025
AISI 420	600 ±15	4.5	15	2–5	700–800 ±18
A756	350 ±10	1.1	70	20–25	850–950 ±20

The intensity of the mass wear of a coating of AISI 420 steel is $4.5·10^{-3}$ mg/m. At the same time, a coating of A756 steel is characterised by higher wear resistance compared to a coating of AISI 420 steel, and the intensity of mass wear of A756 steel is $1.1·10^{-3}$ mg/m. The high wear of the coating made of AISI 420 steel at the initial stages of friction is due to the longer running-in of the coating, containing in its surface increased amounts of γ-Fe in comparison with the coating made of A756.

Such a high wear resistance of a coating made of A756 steel is achieved due to deformation-activated γ→α transformation in the surface layer during friction. From the data of X-ray diffraction analysis (Tab. 2, Fig. 3), it can be seen that in the surface layers of coatings of AISI 420 and A756 steel, after tribological testing, the content of the austenitic phase decreases. In the process of friction of a coating of AISI 420 steel in its surface layers, almost all residual austenite breaks up and its content steel A756 containing an abnormally high amount of metastable austenite (Tab. 2, Fig. 3), the deformation-activated martensitic transformation during friction takes place quite deeply, and the content of metastable austenite decreases to ≈ decreases to 2–5 vol.%. In a coating of martensitic 20–25 vol.% (Tab. 2, Fig. 3d).

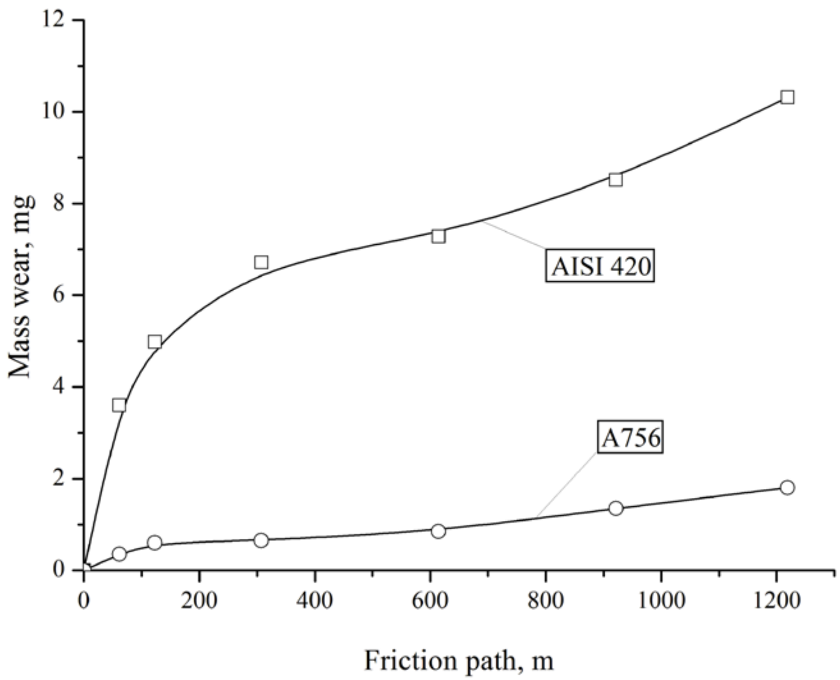

Fig. 2. Dependence of mass wear on the friction path of hypersonic metallisation coatings of high-chromium steels

It should be borne in mind that in a thin surface layer, the content of residual austenite in the coating of A756 steel during friction decreases to almost zero. In deeper layers where shear deformations during friction sharply decrease, the amount of residual austenite remains at the level of its initial content. Since the depth of the scattering layer of X-ray CoK_{α} radiation is ≈ 15–20 μm, the integral content of residual austenite (V_{γ}) in the surface layer of the coating of A756 steel determined by X-ray analysis after friction decreases to a level of ≈ 20–25 vol.%.

Therefore, an HM coating of A756 steel, containing in the initial state an increased amount of metastable austenite, hardens more during friction compared to a coating of AISI 420 steel due to the intensively occurring deformation-activated $\gamma \rightarrow \alpha$ transformation [Kukareko, Belotserkovsky and Grigorchik 2015].

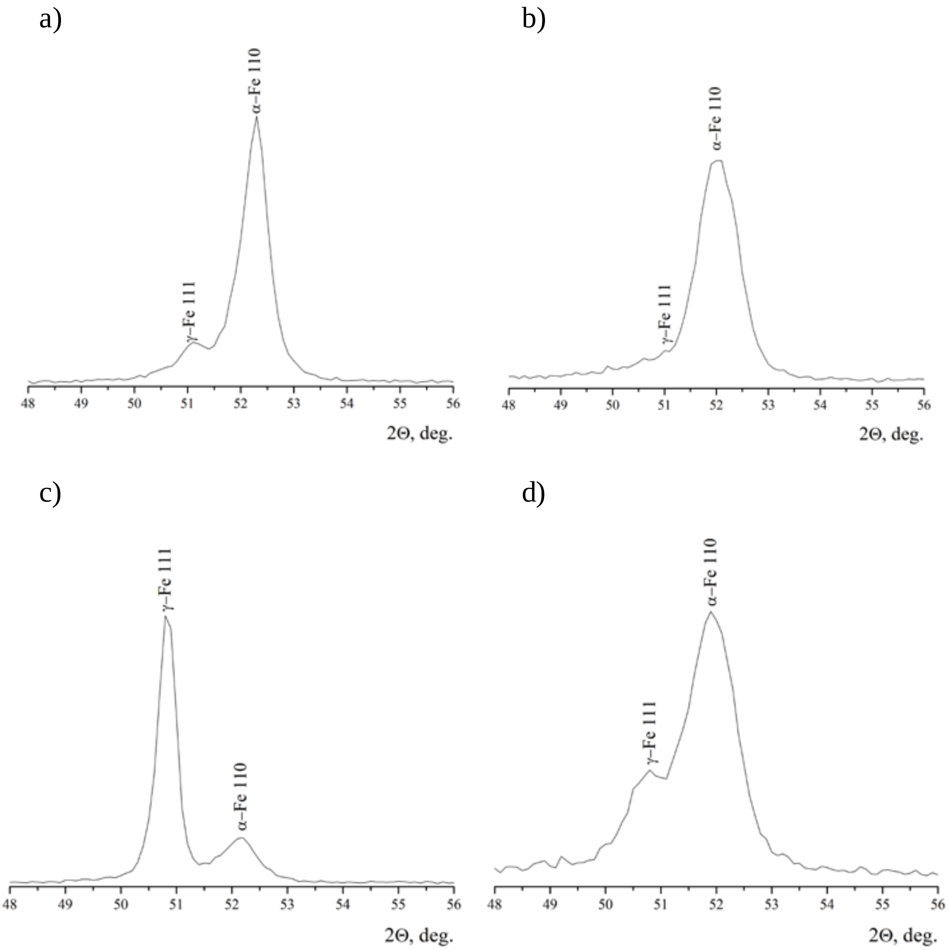

Fig. 3. Fragments of X-ray diffraction patterns (CoK_{α}) from surface layers of coatings from AISI 420 (a, b) and A756 (c, d) steels in the initial state (a, c) and after friction (b, d)

4. CONCLUSIONS

It can be seen that in the coating of A756 steel, an increased amount of phase 70 vol.% is registered in comparison to the coating of AISI 420 steel containing 15 vol.%. The stabilisation of the austenite phase in gas-thermal coatings made of high-chromium martensitic steels is due to their isothermal holding in the region of intermediate bainitic transformation during metallisation and is not associated with accelerated cooling of molten steel drops during crystallisation.

It can also be seen that a coating of A756 steel has a hardness of 350 ±10 HV 10, and for a coating of AISI 420 steel, the hardness is 600 ±15 HV 10. The wear resistance of a coating of A756 steel is ≈ 4 times higher than the wear resistance of a coating of AISI 420 steel, and the intensity of mass wear is $1.1 \cdot 10^{-3}$ mg/m.

The high wear resistance of the coating made of A756 steel is achieved due to the conversion of intensively flowing in the surface layers of the coating during friction. It has been established that during friction of hypersonic metallisation coatings of high-chromium steels, deformation-activated $\gamma \rightarrow \alpha$ transformation in their surface layers leads to a significant increase in microhardness and the wear resistance of coatings. As a result of deformation-activated transformation, the amount of residual austenite in the surface layers of a coating made of A756 steel decreases to 20–25 vol.%, and their microhardness increases to 850–950 ±20 HV 0.025.

REFERENCES

Belotserkovsky, M.A., 2014, *Activation of Process of Electrometallization by a Hypersonic Method*, Proceedings of the 1st International Academic Conference, Science and Education in Australia, America and Eurasia: Fundamental and Applied Science, vol. 1, pp. 162–165.

Belotserkovsky, M.A., Priadko, A.S., Cherepko, A.S., 1997, *Methods and Equipment for the Formation of High-Energy Two-Phase Flows*, Plasma Physics and Plasma Technology, Minsk, 1997, vol. 4, pp. 670–673.

Belyi, A.V., Kukareko, V.A., 2007a, *Inzheneriya poverkhnostey konstruktsionnykh materialov kontsentrirovannymi potokami ionov azota*, Minsk, Belarus.

Belyi, A.V., Kukareko, V.A., 2007b, *The Structural State and Wear Resistance of Chromium Steels Modified with Nitrogen Ions,* The Physics of Metals and Metallography, vol. 104(6), pp. 618–626.

Kukareko, V.A., Belotserkovsky, M.A., Grigorchik, A.N., 2015, *Deformation-Activated Martensitic Transformation in Gas-Thermal Coatings of High-Chromium Steels with Dry Friction*, Abstracts of the International Scientific and Technical Conference “Polokomtrib-2015”, Gomel, Belarus.

Kukareko, V.A., Belyi A.V., Belotserkovsky M.A., Grigorchik A.N., 2013, *Effect of Ion-Beam Nitriding on Structure, Phase State and Tribological Behaviour of Efficient Thermal Spray Coating Deposited from Various Classes of Rad Steels*, Journal of Friction and Wear, vol. 34, no. 6, pp. 475–480.

Kukareko, V.A., Belyi, A.V., Belotserkovsky, M.A., Grigorchik, A.N., 2015, *Structural and Phase States and Wear Resistance of Thermal Spray Coatings of Steels of Various Classes Treated by Nitrogen Ions with Boundary Lubrication*, Journal of Friction and Wear, vol. 36, no. 6, pp. 509–517.

Kukareko, V.A., Grigorchik, A.N., Belotserkovsky, M.A., Sosnovskij, A.V., 2017, *On the Nature of the Formation of a Metastable Austenitic Structure during Gas Thermal Spraying of High-Chromium Martensitic Steel Grade 95Cr18,* Hardening Technologies and Coatings, vol. 13, no. 7(151), pp. 318–322.

Novikov, I.I., 1986, *Teoriya termicheskoy obrabotki metallov. Uchebnik dlya vuzov, 4 izd.*, Moskva.