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HEAT TREATMENT OF HYPERSONIC METALLISATION COATINGS FROM FALSE ALLOYS ON THE BASIS OF ALLOY NI80CR20

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Abstract: The structural-phase state and tribomechanical characteristics of hypersonic metallisation (HM) coatings from false alloys ‘Ni80Cr20 + Al99,3’ and ‘Ni80Cr20 + 08Mn2Si’ in the initial state and after annealing at 550° C and 650°C were investigated. It is shown that annealing of the coating from the false alloy ‘Ni80Cr20 + Al99,3’ leads to a significant increase in its microhardness and wear resistance. In particular, the microhardness of the coating increases ≈ 2 times, and the wear resistance ≈ 19 times in comparison with the initial state. Annealing of the coating from ‘Ni80Cr20 + 08Mn2Si’ leads to a decrease in its microhardness by 1.4 times, and wear resistance decreases by 3.0 times compared with the initial state.

Keywords: high velocity oxygen fuel, false alloys, phase state, structure, wear resistance.

1. INTRODUCTION

Coatings from false alloys obtained by the HM method [Belotserkovsky 2009] have unique properties. In particular, HM coatings from false alloys are, in most cases, characterised by increased strength properties, low oxide content, high corrosion and wear resistance, and low cost compared to steel coatings [Belotserkovsky 2014]. However, despite a number of unique characteristics of HM coatings from false alloys, their physicomechanical properties are inferior to those of monolithic materials. At the same time, the combination of materials (for example, steel and non-ferrous alloys) in sprayed alloys significantly expands the possibilities of increasing their strength and tribomechanical properties, due to the release of intermetallic phases in them during additional heat treatment. It was shown in [Kukareko 2019] that annealing of HM coatings containing iron and aluminum leads to a significant increase in their tribomechanical characteristics compared to the initial state and steel coatings due to the separation of intermetallic phases in the heat-treating coating. At the same time, there are intermetallic compounds with higher strength properties in comparison with the iron-aluminum phases. It is known that nickel intermetallic compounds possess a number of unique properties, including increased hardness and wear resistance. In this regard, the aim of this work was to study the effects of the annealing of HM coatings from false alloys based on the Ni80Cr20 alloy and its structural-phase state and tribomechanical properties.

2. OBTAINING SAMPLES AND RESEARCH METHODS

As the objects of research, HM coatings from the false alloys 'Ni80Cr20 + Al99,3' and 'Ni80Cr20 + 08Mn2Si' were chosen. Coatings were sprayed using the hypersonic metallisation using the ADM-10 unit [Kukareko and Belotserkovsky]. Coatings were sprayed at 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 diameters of the wires used: Ni80Cr20 – 1.8 mm, Al99,3 – 2.0 mm, 08Mn2Si – 1.6 mm.

The chemical composition of sprayed false alloys is presented in Table 1.

Table 1. The chemical composition of the sprayed false alloys 'Ni80Cr20 + Al99,3' and 'Ni80Cr20 + 08Mn2Si'

Material of coatings	Content, mas. %								
	Al	Si	S	P	Cr	Mn	Fe	Zn	Ni
Ni80Cr20 + Al99,3	50.97	1.43	0.05	0.04	10.62	0.24	0.76	0.02	rest
Ni80Cr20 + 08Mn2Si	0.41	0.87	0.01	0.03	11.58	0.77	40.13	0.02	rest

The HM coatings were sprayed onto a substrate (70×70×5 mm) of steel 20. The thickness of the sprayed coatings was 1.2–1.5 mm. The study of the structural phase composition and tribotechnical properties was carried out on cut samples with sizes of 8×6×5 mm.

Heat treatment of coating samples was carried out in a chamber furnace with a stationary hearth SNOL 7.2 / 1100. The annealing temperature of the coatings was 550° C and 650° C. The exposure time was 30 minutes for coatings from 'Ni80Cr20 + 08Mn2Si' and 60 minutes for coatings from 'Ni80Cr20 + Al99,3'. Cooling was carried out in air.

The phase composition of the coatings was studied on a DRON-3.0 diffractometer in monochromatised cobalt (CoK_{α}) radiation at a voltage of 28 kV and an anode current of 14 mA. The radiographs were decrypted using Crystallographica Search-Match software with a PDF-2 card index. Metallographic studies were carried out on an Altami MET 1MT optical microscope using AltamiStudio 3.3 software.

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 HV 10 was used as a counterbody. 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.

3. RESEARCH RESULTS AND DISCUSSION

As a result of hypersonic metallisation of false alloys 'Ni80Cr20 + Al99,3' and 'Ni80Cr20 + 08Mn2Si', coatings are formed having a layered structure and low porosity (Fig. 1 a, b). In particular, the porosity of coatings from false alloys did not exceed ≈ 3–5 vol. %.

From the presented microstructures (Fig. 1), it can be seen that annealing of HM coatings from the false alloy 'Ni80Cr20 + Al99,3' at 550°C and 650°C leads to a significant increase in their porosity. In particular, the porosity of the coatings annealed at 550°C and 650°C is 13 and 16 vol. %. The porosity of the coatings made of the false alloys 'Ni80Cr20 + 08Mn2Si' as a result of annealing at similar temperatures increases slightly (Fig. 1). The increase in porosity during annealing of coatings made of 'Ni80Cr20 + Al99,3' is due to the realisation of the Frenkel and Kirkendall effects [Kryshtal 1972; Bokshteyn 1978]. They consist in the fact that when two dissimilar welded materials are annealed, atoms of a more active material (in our case, aluminum) are diffused by the vacancy mechanism, while the vacancies move in the direction opposite to the flow of diffusing aluminum atoms. As a result, the interface between the two materials is shifted and the formation of diffusion porosity. At the same time, annealing temperatures of 550°C and 650°C, in the case of annealing of coatings made of 'Ni80Cr20 + 08Mn2Si', do not lead to high diffusion mobility of iron and nickel atoms.

The phase composition of HM coatings from the false alloys 'Ni80Cr20 + Al99,3' and 'Ni80Cr20 + 08Mn2Si' in the initial state and after annealing is presented in Table 2.

It can be seen that in the initial state, the coating of the false alloys 'Ni80Cr20 + Al99,3' contains γ-(Ni, Cr) and Al phases (Table 2).

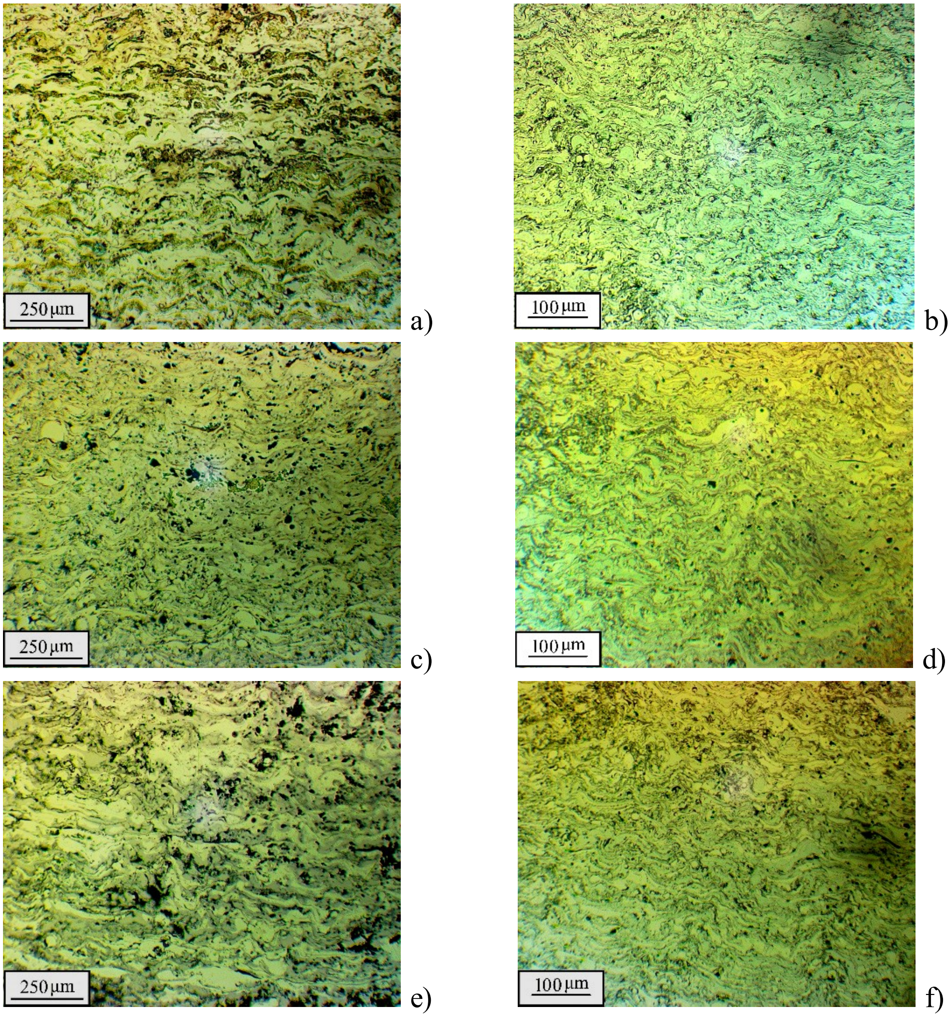

Fig. 1. Typical microstructures of HM coatings from the false alloys 'Ni80Cr20 + Al99,3' (a, c, d) and 'Ni80Cr20 + 08Mn2Si' (b, d, f) in the initial state (a, b) and after annealing at 550°C (c, d) and 650°C (e, f)

The hardness of the sprayed coating 'Ni80Cr20 + Al99,3' is 160 HV 10, and its microhardness is 250 HV 0.025 (Table 2). Annealing of the coating from the false alloys 'Ni80Cr20 + Al99,3' at 550°C for 60 minutes leads to the formation of Al_3Ni, NiAl, Ni_2Al_3, Ni_3Al intermetallics in the matrix γ-(Ni, Cr) phase. In this case, the hardness of the coating increases to 245 HV 10, and its microhardness 470 HV 0.025 (Table 2). A further increase in the temperature of annealing of the coating from

'Ni80Cr20 + Al99,3' to 650°C leads to an increase in the number of intermetallic phases Ni_2Al_3, NiAl, Ni_3Al in γ-(Ni, Cr). The hardness and microhardness of the coating from 'Ni80Cr20 + Al99,3' as a result of annealing at 650°C increases to 285 HV 10 and 530 HV 0.025 (Table 2), respectively. A significant difference between the values of hardness and microhardness of the annealed false alloys are associated with a significant increase in its porosity.

Table 2. Phase composition of HM coatings from false alloys 'Ni80Cr20 + Al99,3' and 'Ni80Cr20 + 08Mn2Si' in the initial state and after annealing

Specimen	Phase composition	HV 0.025	HV 10
Ni80Cr20 + Al99,3	γ-(Ni,Cr); Al	250	160
Ni80Cr20 + Al99,3, annealing 550°C, 60 min	γ-(Ni,Cr); Al_3Ni; NiAl; Ni_2Al_3; Ni_3Al	470	245
Ni80Cr20 + Al99,3, annealing 650°C, 60 min	γ-(Ni,Cr); Ni_2Al_3; NiAl; Ni_3Al	530	285
Ni80Cr20 + 08Mn2Si	α-Fe; γ-(Ni,Cr); Ni_3Fe; NiFe; Fe_3O_4	500	355
Ni80Cr20 + 08Mn2Si, annealing 550°C, 30 min	α-Fe; γ-(Ni,Cr); Ni_3Fe; NiFe; Fe_3O_4	470	300
Ni80Cr20 + 08Mn2Si, annealing 650°C, 30 min	γ-(Ni,Cr); α-Fe; NiFe; Ni_3Fe; Fe_3O_4	360	270

The phase α-Fe, γ-(Ni, Cr), Ni_3Fe, NiFe, Fe_3O_4 are recorded in the phase composition of the sprayed HM coating from the false alloy 'Ni80Cr20 + 08Mn2Si' (Table 2). It should be noted that during the spraying process, a large amount of Ni_3Fe and NiFe intermetallic compounds are formed in the 'Ni80Cr20 + 08Mn2Si' coating. The hardness of the false alloy after deposition is 355 HV 10, and its microhardness is 500 HV 0.025 (Table 2). Annealing of the coating from 'Ni80Cr20 + 08Mn2Si' at 550°C for 30 minutes leads to a decrease in the amount of Ni_3Fe intermetallic in it and an increase in the content of the NiFe phase.

This change in the phase composition of the false alloy 'Ni80Cr20 + 08Mn2Si' leads to a decrease in the values of hardness and microhardness to 300 HV 10 and 470 HV 0.025 (Table 2). An increase in the annealing temperature of the coating from 'Ni80Cr20 + 08Mn2Si' to a temperature of 650°C leads to a substantial increase in the NiFe intermetallic content in it and a decrease in the amount of Ni_3Fe.

As a result of annealing of the coating from 'Ni80Cr20 + 08Mn2Si' at 650°C, its hardness and microhardness decrease to 270 HV 10 and 360 HV 0,025 (Table 2). A decrease in the properties of the false alloy 'Ni80Cr20 + 08Mn2Si' with an increase in the annealing temperature is associated with a decrease in the content of Ni_3Fe intermetallic in it.

The results of tribological tests are presented in Figure 2 and in Table 3.

Table 3. The intensity of the mass wear of HM coatings from the false alloys 'Ni80Cr20 + Al99,3' and 'Ni80Cr20 + 08Mn2Si' in the initial state and after annealing

Specimen	Mass wear rate in dry friction, $\cdot 10^{-3}$ mg/m
Ni80Cr20 + Al99,3	29.0
Ni80Cr20 + Al99,3, annealing 550°C, 60 min	11.5
Ni80Cr20 + Al99,3, annealing 650°C, 60 min	1.5
Ni80Cr20 + 08Mn2Si	9.0
Ni80Cr20 + 08Mn2Si, annealing 550°C, 30 min	10.5
Ni80Cr20 + 08Mn2Si, annealing 650°C, 30 min	30.0

From the results of tribotechnical tests, it can be seen that the coating from the false alloy 'Ni80Cr20 + 08Mn2Si' has higher wear resistance compared to the coating from the false alloy 'Ni80Cr20 + Al99,3' (Fig. 2, Table 3). In particular, the mass wear rate of the false alloy 'Ni80Cr20 + 08Mn2Si' is $9.0 \cdot 10^{-3}$ mg/m, and the false alloy 'Ni80Cr20 + Al99,3' is $29.0 \cdot 10^{-3}$ mg/m (Table 3).

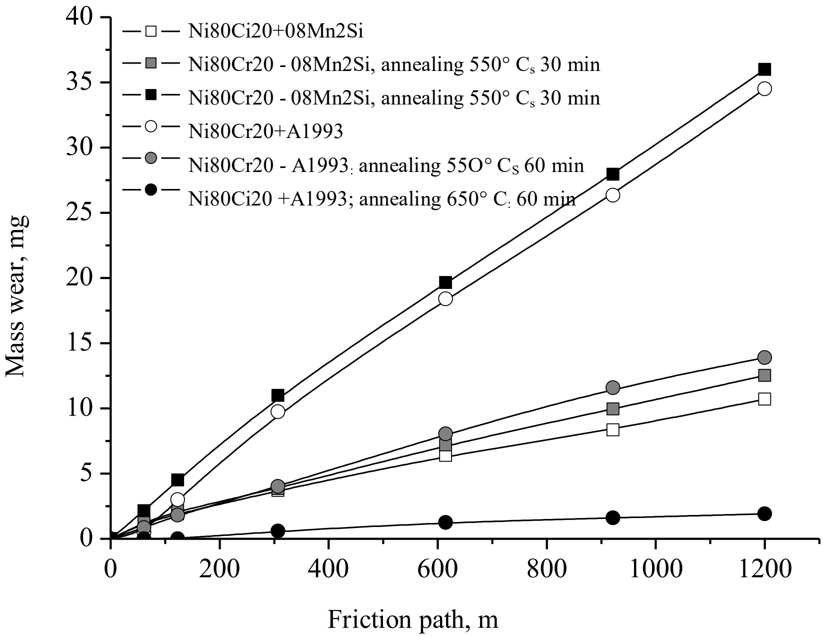

Fig. 2. Dependences of mass wear of HM coatings from false alloys from the friction path

The increased wear resistance of the false alloy ‘Ni80Cr20+ 08Mn2Si’ coating is associated with the presence in its phase composition of from false alloys from the friction path Ni_3Fe intermetallic formed during sputtering (Table 2). As a result of annealing of coatings from the false alloy ‘Ni80Cr20 + Al99,3’ and ‘Ni80Cr20 + 08Mn2Si’ at 550°C, their wear resistance is approximately equal (Fig. 2, Table 3). This is due to the insignificant softening of the coating from ‘Ni80Cr20 + 08Mn2Si’ due to a decrease in the amount of the Ni_3Fe phase in it and to a significant hardening of the coating from ‘Ni80Cr20 + Al99,3’ due to the precipitation of the intermetallic phases Al_3Ni, NiAl, Ni_2Al_3, Ni_3Al in it (Table 2). An increase in the temperature of annealing of coatings from the false alloy ‘Ni80Cr20 + Al99,3’ to 650°C leads to an even more significant increase in their wear resistance (Table 3). In particular, the wear resistance of the annealed ‘Ni80Cr20 + Al99,3’ coating at 650°C is ≈ 19 times higher than its wear resistance in the initial state (Fig. 2, Table 3). The increase in the wear resistance of the ‘Ni80Cr20 + Al99,3’ coating after annealing at 650°C is due to the release of a large amount of durable Ni_2Al_3 intermetallic and NiAl, Ni_3Al intermetallic compounds (Table 2). At the same time, the thermal treatment of the coating from the false alloy ‘Ni80Cr20 + 08Mn2Si’ at 650°C leads to a sharp decrease in its wear resistance (Table 3), which is associated with the almost complete dissolution of the Ni_3Fe intermetallic in it and the formation of a less durable NiFe phase (Table 2).

Thus, it can be concluded that annealing of HM coatings from false alloys ‘Ni80Cr20 + Al99,3’ leads to a significant increase in their hardness/microhardness and wear resistance. At the same time, heat treatment of coatings of ‘Ni80Cr20 + 08Mn2Si’ leads to a decrease in their properties.

4. CONCLUSIONS

The structural-phase state and tribomechanical characteristics of hypersonic metallisation coatings from the false alloys ‘Ni80Cr20 + Al99,3’ and ‘Ni80Cr20 + 08Mn2Si’ in the initial state and after annealing at 550° C and 650°C were studied.

It is shown that spraying of the false alloys ‘Ni80Cr20 + 08Mn2Si’ forms a coating that contains Ni_3Fe and NiFe intermetallics in its phase composition. The microhardness of this coating is 500 HV 0.025. Annealing of the coating from the false alloy ‘Ni80Cr20 + 08Mn2Si’ at 550°C and 650°C for 30 minutes leads to a decrease in the content of Ni_3Fe intermetallic in its phase composition and an increase in the amount of NiFe phase, which in turn leads to a decrease in the microhardness and wear resistance of the coating. In particular, annealing of the coating leads to a decrease in wear resistance up to 3.0 times in comparison with the initial state.

The coating from the false alloy ‘Ni80Cr20 + Al99,3’ contains γ-(Ni, Cr) and Al in the phase composition, and its microhardness is 250 HV 0.025. It was established that annealing of coatings from the false alloy 'Ni80Cr20 + Al99,3' at 550°C and 650°C for 60 minutes leads to a significant change in its phase composition and an increase in porosity to 13–16 vol. %. Intermetallic compounds Al_3Ni, NiAl, Ni_2Al_3, Ni_3Al are registered in heat-treated coatings made of 'Ni80Cr20 + Al99,3', and their microhardness and wear resistance increase ≈ 2 times and ≈ 19 times compared to the initial state.

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