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Deposition and Characterization of NiCoCrAlY Coatings by Multi-chamber Detonation Sprayer

M.G. Kovaleva[1,*], Y.N. Tyurin[2,†], M.Y. Arseenko[1], M.S. Prozorova[1], V.V. Sirota[3], B.M. Beresnev[4], I.A. Pavlenko[3], K.N. Mamunin[3]

[1] *Belgorod State National Research University, Joint Research Center,*
85, Pobedy Str., 308015 Belgorod, Russia
[2] *Paton Electric Welding Institute NANU, 11, Bozhenko, 03650 Kyiv, Ukraine*
[3] *Belgorod State National Research University, Center for constructional ceramics and*
engineering prototyping, 85, Pobedy Str., 308015 Belgorod, Russia
[4] *National Kharkov University, 4, Svobody Sq., 61022 Kharkiv, Ukraine*

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In this study, multi-chamber detonation sprayer (MCDS) was applied for deposition of NiCoCrAlY powder coatings (60-65 μm thick) on nickel base superalloy JS6U (Russia). Powder RPCoCr27Al7Si3Y was used to deposit of a coating. The coating microstructures and phase compositions were characterized using SEM, OM and XRD techniques. Measurement of the microhardness of samples was done with a micro-hardness tester DM – 8B using a Vickers's indenter with load on of 0.01 N. It was established that MCDS has provided the conditions for formation of a dense layer with porosity below 1% and microhardness of 1100 ± 250 $HV_{0.1}$.

Keywords: Detonation, Sprayer, Powder, Coating, Microstructure, Porosity, hardness.

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1. INTRODUCTION

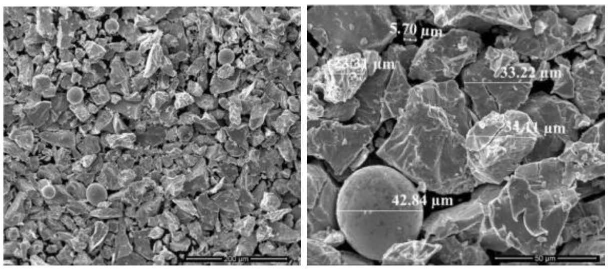
Superalloys are the most reliable and cost effective structural material widely used in aircraft and industrial gas turbine applications [1,2]. The superalloys surface does not have adequate level of such critical elements as Al and Cr to impact oxidation and corrosion resistance for complete service live of produced components. Increasing Al and Cr concentration, therefore, would apparently be a logical solution to increase oxidation capability and high-temperature corrosion resistance [3]. Protective coatings can be applied to increase the durability and field performance. MCrAlY's are a family of materials, which have a base metal (M) of cobalt, nickel and/or iron, plus chromium, aluminium, yttrium and sometimes other alloying elements. MCrAlY's are used as overlay coating for turbine components improving their resistance and provide a longer lifetime for turbine even under hard environmental conditions. High temperature oxidation resistance is achieved by one or more alloy components, which have to form a dense, stable, slow-growing, external oxide layer such as Al_2O_3 [4]. The MCrAlY coatings can be deposited by electron beam physical vapor deposition (EB-PVD), chemical vapor deposition, plasma spraying, high-current pulsed electron beam (HCPEB) [5] and other methods [6,7]. However, there exist some problems, e.g. porosity and rough surface morphology on bond coatings, associated with thermal sprayed methods, which will influence the surface duration of a post-deposited top coating [5,8].

The aim of this paper is to investigate the microstructure and microhardness of NiCoCrAlY powder coating obtained on nickel base superalloy JS6U through a new method of powder acceleration which allows achieving the powder velocity of 1400 m/s.

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of Coating

Powder RPCoCr27Al7Si3Y (d(0.1): 10,12 μm, d(0.5): 37,63 μm, d(0.9): 66,51 μm) (Fig. 1) was used to deposit a dense layer upon the plate of 30 x 30 x 5 (mm) on nickel base superalloy substrate. The powder consisted of crushed particles with an average particles size of 40.66 μm.



a b

Fig. 1 – SEM images of the RPCoCr27Al7Si3Y powder (Quanta 600 FEG, accelerating voltage – 15 kV)

The powder RPCoCr27Al7Si3Y consists of NiCrFe with a cubic lattice structure (a = 2.87 Å), Co with a cubic lattice structure (a = 3.55 Å), AlNi with a cubic lattice structure (a = 2.87 Å), AlCo with a monoclinic lattice structure (a = 8.55 Å, b = 6.29 Å, c = 6.12 Å), AlFeSi with a hexagonal lattice structure (a = b = 12.35 Å, c = 26.11 Å).

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[*] Kovaleva@bsu.edu.ru
[†] ytyurin@i.com.ua

Flat specimens of nickel base superalloy JS6U (Russia) (Ni-10Cr-10Co-10W-5Al-3Ti-2Mo-5Nb, all in wt pct) were used as substrates, and they were sandblasted by alumina grits 25A F360 prior to spraying. The specimens were transversally cut by spark erosion, mechanically polished and prepared by standard metallographic methods of sample preparation [9] - sectioning, mounting and polishing [10]. The sample was prepared by grinding with abrasive SiC paper (gradation 200, 500, 800, 1000), followed by polishing with 1 μ diamond slurry according to the procedure recommended by Struers company for ceramic coatings.

In the present study, a multi chamber, vertically mounted detonation sprayer (MCDS) (Fig. 2) [11,12] with a barrel length of 300 mm was employed to deposit the RPCoCr27Al7Si3Y powder coating upon a nickel base superalloy substrate.

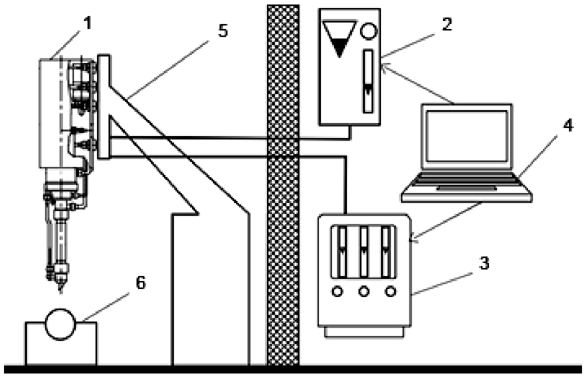


Fig. 2 – Equipment for deposition of coatings

The automated equipment (Fig. 2) consists of: 1 - device for spraying, 2 - standard powder feeder with a feed rate of up to 3 kg/h, 3 – a standard low-pressure (max. 0.3 MPa) gas panel for feeding oxygen, propane-butane and air, 4 – an automated control system for the technological process, 5 – an automated manipulators for moving MCDS and 6 – a specimen holder.

Table 1 – Flow rate of gas and consumption of powder in detonation device

Flow rate of fuel mixture components, [m^3/h]			**Powder consumption, [g/h]**
Oxygen	Propane (30%) + butane (70%)	Air	
*2.7/ **3.0	*0.9/ **0.7	*1.37/**1.39	720
*Cylindrical form combustion chamber. **Combustion chamber in the form of a disk.			

NiCoCrAlY coatings prepared with due regard for the summarized in Table 1 parameters. Coatings were deposited with a transverse displacement 9 mm and an eight-time repetition. Speed of moving was 2000 mm/min, distance from the sample - 50 mm. A barrel with a throat diameter of 18 mm was adopted.

2.2 Features of Powder and Coatings

The microstructure and elemental composition of the powder and coatings were determined by using the scanning electronic microscopes (SEM) Quanta 200 3D, Quanta 600 FEG and Optical Microscope (OM) Olympus GX 51. Porosity was determined by the metallographic method with elements of the qualitative and quantitative analysis of the geometry of the pores by using optical inverted microscope Olympus GX51 [13]. Ten arbitrarily selected micrographs for each experimental point were registered in optic microscope (in the bright field, magnified 500x) using "SIAMS Photolab" programme. Local phase and diffraction analysis was conducted by using X-ray powder diffractometer Rigaku Ultima IV. Micro-hardness was measured with automatic micro-hardness tester DM-8B (Affri) by Vickers's test at a test load 10 g. Indentation was carried out on cross-sections of the samples of the coatings, the distance between the indents being 20 μm. In the average, 10 tests were used as an indicator of the coating hardness.

3. RESULTS AND DISCUSSION

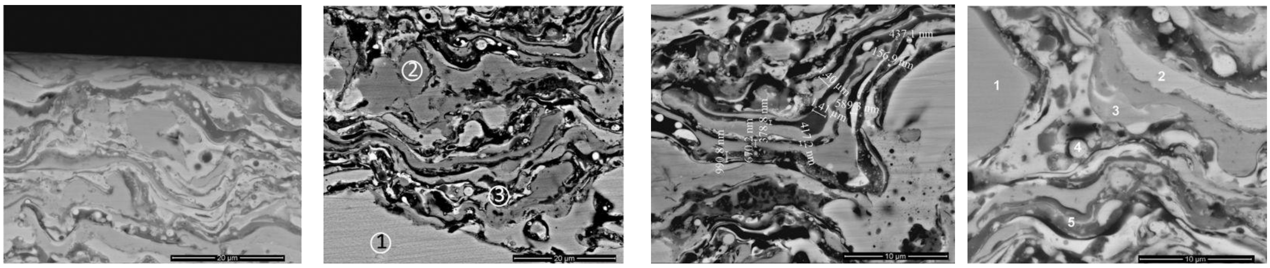
3.1 SEM observation of the system «coating - substrate»

The thickness of deposited coatings ranged about 60-65 μm (Fig. 3). Fig. 3 and Table 2 demonstrate the SEM images and elemental composition of the cross-sectional of NiCoCrAlY powder coating. The coating shows a very dense microstructure consisting of well-flattened particles, which indicates that the most of the powder particles were melted before deposition. The obtained coating consists of remelted splats "flattened powder particles", small amount of porosity, unmelted particles and oxide scale. It is a consequence of interpass oxidation during thermal spraying. The porosity of the coating NiCoCrAlY was below 1 %.

Detonation spraying is associated with high temperatures and velocities of the moving powder particles with the result that large fractions of the powder are melted, and small are melted completely with the deposition of the appropriate alternating layers. The process of the detonation combustion in the multi-chamber detonation sprayer allows getting increase in particles velocity [14].

Table 2 – The elemental composition of coating

Point	**Wt%**						
	Ni	**Co**	**Cr**	**Al**	**Fe**	**O**	**C**
1	5.54	57.31	17.39	10.47	1.69	1.55	3.74
2	3.74	47.76	25.00	6.17	2.04	3.57	3.57
3	5.36	53.30	18.90	9.56	1.76	2.49	4.42
4	13.56	43.95	20.79	5.34	1.52	5.45	4.79
5	3.62	43.38	19.54	8.06	1.85	12.53	4.41



a b c d

Fig. 3 – SEM images of cross-section of coating - Quanta 200 3D (a), Quanta 600 FEG - back-scattered electron mode (b,c) and elemental compositions of coating (d) (Table 2)

3.2 XRD analysis of the coating

The results of the XRD analysis of the coatings are shown in Fig. 4. The NiCoCrAlY coating consists of Co with a cubic lattice structure (a = 3.56 Å), Co_3O_4 with a cubic lattice structure (a = 8.22 Å) phases, Ni–Cr–Fe with a cubic lattice structure (a = 2.87 Å), $AlNi_3$ with a tetragonal lattice structure (a = b = 3.56 Å, c = 7.15 Å), $Al_{0.9}Ni_{12.5}Si_{8.1}$ with a trigonal lattice structure (a = 7.69 Å, c = 14.59 Å), $Fe_3((Si_{1.4}Fe_{0.6})O_5)(OH)_4$ with a trigonal lattice structure (a = 5.53 Å, c = 7.15 Å) phases as identified by XRD analysis shown in Fig. 4.

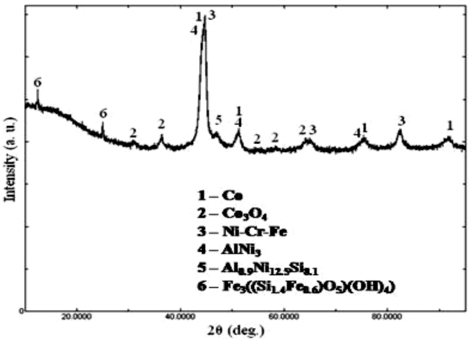


Fig. 4 – XRD pattern of the NiCoCrAlY powder coating

3.3 Micro-hardness of the system «coating - substrate»

It was established that hardness of the fine lamellae in the coatings was 1250±250 $HV_{0.1}$ (Fig. 3b, point 3), this being 2-3 times higher that of the substrate material. The unmelted particles (Fig. 3b, point 2) had a hardness of 900±250 $HV_{0.1}$.

Results indicated also that NiCoCrAlY powder coating has higher hardness values (1100 ± 250 $HV_{0.1}$) that the nickel base superalloy substrate (500 ± 250 $HV_{0.1}$) (Fig. 3b, point 1). The hardness variation along the coat thickness is no uniform which may be attributed to the phase compositions of the coating and due to the size of the indentation marks produced at 10 g, the measurements performed in the vicinity of the substrate are increasingly affected by the latter.

4. CONCLUSIONS

The NiCoCrAlY coating on the flat specimens of nickel base superalloy JS6U were produced by a multichamber detonation sprayer. The MCDS application allows to form a dense hard layer with porosity below 1 %. Results of this work open up new prospects for further elaboration of new technologies to making protective NiCoCrAlY coatings which can enhance properties of nickel base superalloy.

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