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Obtaining multilayer coatings by the detonation spraying method

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This work were studied the effect of technological parameters of detonation spraying on the phase composition and tribological characteristics on the bases of NiCr and Al_2O_3 coatings. As well as there was obtained and investigated multilayer coating on the bases of NiCr/NiCr- Al_2O_3 / Al_2O_3 . It was determined that during detonation spraying the phase composition of Al_2O_3 coatings strongly depends on the degree of filling the borehole with a gas mixture. The α - Al_2O_3 -phase content in the coatings increases when the degree of filling is 63% and 54%. Only one $CrNi_3$ phase is observed on the diffractograms and only increase of reflex intensity (020) at barrel filling by 58% is observed by sputtering on the bases of NiCr coatings in different degrees of barrel filling. The results of the coating nanohardness study showed that the hardness of the Al_2O_3 coating increases depending on the content of α - Al_2O_3 in it. Al_2O_3 coating has the maximum nanohardness values and is 16.42 GPa at the borehole is filled to 63%. The nanohardness of NiCr coating has the maximum values at barrel filling by 58% and consisting of 8.02 GPa.

Keywords: detonation spraying, multilayer coating, NiCr, Al_2O_3, phase, hardness.

Introduction

One of the most serious problems in modern technology is the necessity to ensure conformity between the properties of materials used in various branches of production and the increasingly harsh conditions of their operation. Usually the weakest link of assemblies and parts is their surface, which is exposed to multifactor loads. It is possible to improve the properties of used materials by hardening them with coatings.

Recently, there has been a great deal of interest in high-speed coating technologies that are characterized by high productivity, versatility, ease of automation, and virtually unlimited sizes of surfaces to be coated. High-speed spraying processes can significantly expand the capabilities of conventional thermal spraying of coatings used to protect parts from wear, corrosion, etc. Gas-thermal high-speed methods of coating production include methods of detonation, supersonic air-gas plasma spraying (SAGPS) and high volume of flame (HVOF) spraying [1-4]. Among them, detonation spraying is the most promising. Detonation spraying is carried out using a special detonation gun filled with an explosive gas mixture. Powder sprayed material is used to form the coating. The detonation process accelerates the powder particles to high speeds (up to 1000 m/s), melting them and depositing them on the sprayed surface. The advantages of this method are: low porosity of the coating, high bonding strength with the base of the processed part, low thermal impact, which allows avoiding undesirable thermal stresses and warping even of thin-walled parts of complex design [5-7].

It is necessary to increase their performance characteristics, a combination of high values of various properties (bonding strength, wear resistance, corrosion resistance, etc.) to increase the durability of detonation coatings working in severe conditions. One of the most effective ways to solve this problem is to obtain multilayer coatings. The most promising are multilayer coatings having a gradient structure, the characteristic feature of which is a smooth change in the chemical composition, structure and properties (physical, mechanical, etc.) along the thickness of the coating [8, 9]. Also the multilayer structure can be an effective method of increasing the corrosion resistance of coatings. The interfaces between the layers can act as protective barriers in an aggressive environment [10-13].

In this connection, the aim of this work is to study the effect of technological parameters on the properties of NiCr and Al_2O_3 coatings and the production multilayer coatings on the bases of NiCr /NiCr-Al_2O_3 / Al_2O_3 with having a gradient structure.

Materials, equipment and research methods

Powder of NiCr, Al_2O_3 and NiCr-Al_2O_3 (50/50) with a dispersion of 20-45 μm was used as the sputtering material. The coatings were applied to samples made of 12X18H10T steel by detonation spraying on a CCDS2000 (Computer Controlled Detonation Spraying) detonation machine. Figure 1 shows a schematic diagram of the CCDS2000 detonation facility. The coating is applied with a detonation gun, the barrel of which is filled with an explosive gas mixture, a dosed portion of the powder is thrown into the barrel, and an electric spark excites detonation. The detonation products heat the powder particles until they melt and throw them at high velocity onto a part mounted in front of the cannon barrel. On impact, micro-welding occurs and the powder is firmly (on a molecular level) bonded to the surface of the part. After each shot, the barrel is purged with nitrogen to clean the detonation products residue. The required thickness is built up by a series of successive series of shots, during which the object can be moved using a manipulator [14, 15].

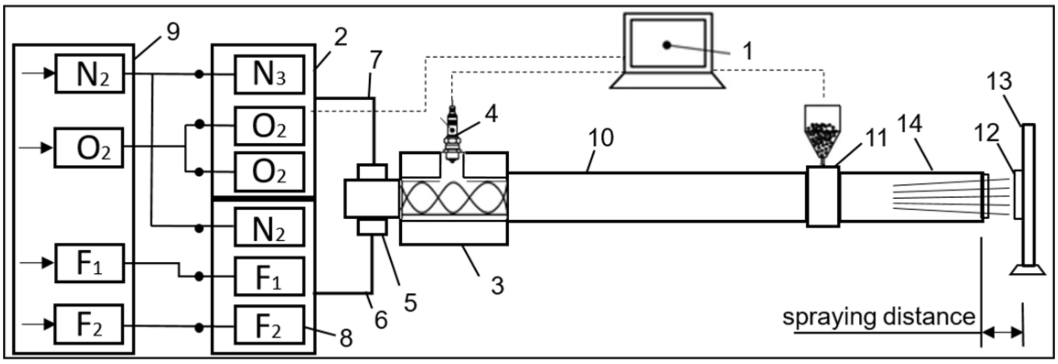

Figure 1. Schematic diagram of CCDS2000 detonation system: 1-control computer, 2-gas distributor, 3-mixing-ignition chamber, 4-spark plug, 5-barrel valve, 6-fuel line, 7-oxygen line, 8-gas valves, 9-gas supply unit, 10-breech block, 11-powder batcher, 12-workpiece, 13-manipulator, 14-muzzle of the barrel.

Coatings on the basis of NiCr and Al_2O_3 were obtained at different values of the barrel filling volume. An acetylene-oxygen mixture was used as a combustible gas, which is the most demanded fuel in detonation spraying of powder materials. As the amount of explosive mixture increases (from 25 to 60% of the barrel volume), the temperature to which the particles are heated during their movement inside the barrel increases. Technological parameters of obtaining NiCr and Al_2O_3 coatings are shown in Table 1.

Table 1.
Technological parameters for obtaining NiCr-Al_2O_3 coatings.

Number of the sample	Powder name	Volume of barrel filling, %	Number of shots
1	Al_2O_3	45	20
2	Al_2O_3	54	20
3	Al_2O_3	63	20
4	NiCr	54	20
5	NiCr	58	20
6	NiCr	65	20

The multilayer coating on the bases of NiCr/NiCr-Al_2O_3 / Al_2O_3 was also obtained by successive spraying of three kinds of powder: 1-NiCr, 2-mixture of NiCr powders (50%) and Al_2O_3 (50%), 3-Al_2O_3. The sputtering mode of the multilayer coating on the bases of NiCr/NiCr-Al_2O_3 / Al_2O_3 is shown in Table 2.

Table 2.
Technological parameters for the multilayer coating on the bases of NiCr/NiCr-Al_2O_3 / Al_2O_3.

Layer	Powder name	Volume of barrel filling, %	Number of shots
1	NiCr	54	20
2	NiCr-Al_2O_3	54	20
3	Al_2O_3	63	20

X-ray phase studies of the samples were performed by X-ray structural analysis on X'PertPRO diffractometer. Diffractograms were taken using CuKα-radiation (λ=2.2897 Å) at 40 kV and a current of 30 mA. The diffractograms were interpreted using HighScore software. Mechanical properties of the obtained coatings (Young's modulus, nanohardness) were investigated with the help of nanohardness meter NanoScan-4Dcompact. Nanoindentation of the coatings was performed by the Oliver and Farr method using a Berkovich indenter at a load of 100 Mn (ASTM E2546-07). The cross-sectional morphology of the samples was examined by scanning electron microscopy (SEM) using backscattered electrons (BSE) on a JSM-6390LV scanning electron microscope at accelerated stress.

Results and discussion of studies

Figure 2 presents the diffractograms of Al_2O_3 coatings obtained at different degrees of barrel filling volume. The figure shows that the phase composition of Al_2O_3 coatings changes depending on the degree of barrel filling. The intensity of α-Al_2O_3-phase peaks increases at barrel is filled by 63% and 54%, indicating an increase in the concentration of α-Al_2O_3-phase. At filling of the shaft by 45% the coating consists mainly of γ-Al_2O_3-phase. The change in the phase composition of Al_2O_3 coatings is related to the temperature of powder heating in the spraying process. Since, the powder temperature changes depending on the volume of barrel filling.

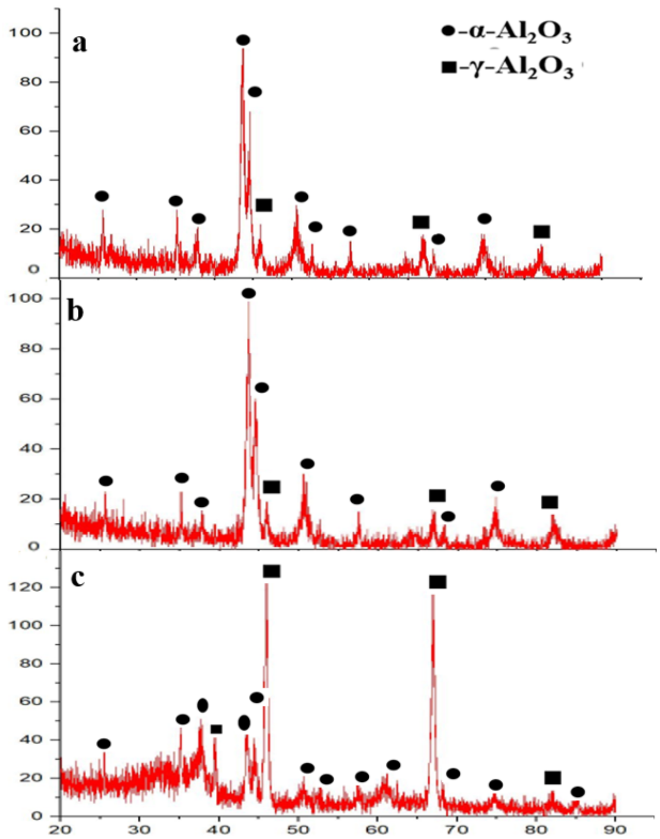

Figure 2. Diffractograms of Al_2O_3 coatings obtained at barrel filling volume 63% (a), 54% (b), 45% (c).

Diffractograms on the bases of NiCr coatings obtained at different degrees of barrel filling are shown in Figure 3. The figure shows that all coatings consist of $CrNi_3$. At the same time, an increase in the reflex intensity (020) is observed when the barrel is filled to 58%.

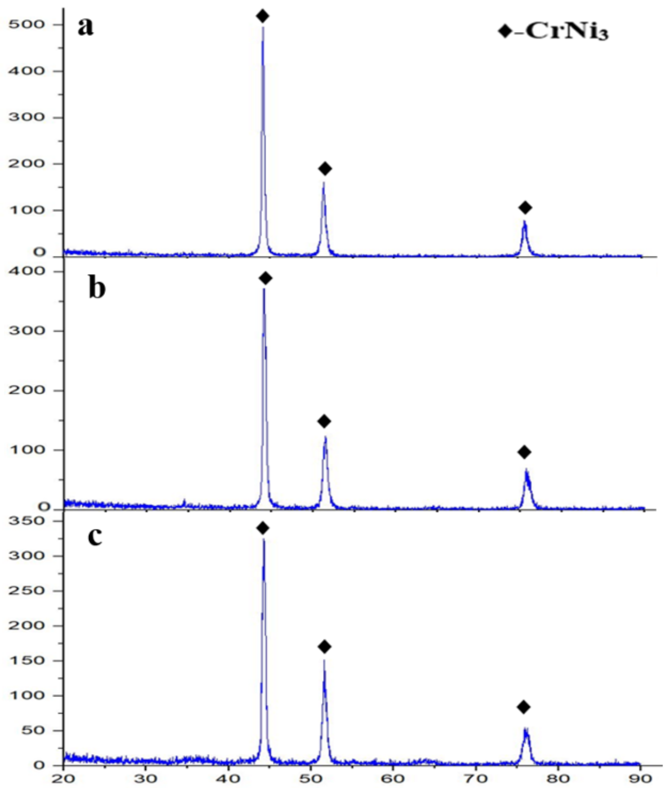

Figure 3. Diffractograms of the NiCr coatings received at filling 58% (a), 54% (b), 65% (c).

The results of research of nanohardness and modulus of elasticity of coating are presented in the Table 3. The results of the coating nanohardness study showed that the hardness of the Al_2O_3 coating increases as a function of its α-Al_2O_3 content. The Al_2O_3 coating has a maximum nanohardness value of 16.42 GPa when the borehole is filled with 63%. The increase in hardness of Al_2O_3 coatings with increasing α-Al_2O_3-phase in it is quite natural. Since, α-Al_2O_3 has a higher hardness and wear resistance than γ-Al_2O_3. The nanohardness of the NiCr coating has maximum values when the barrel is filled to 58% and is 8.02 GPa. The small difference in hardness of NiCr coatings is apparently due to the porosity of the coating, which changes depending on the spraying mode. The table also shows the elastic modulus data. The table shows that the modulus of elasticity of all coatings varies with hardness.

On the bases of study of sputtering mode influence on the structure and properties of NiCr and Al_2O_3 coatings, we obtained multilayer coating on the bases of NiCr/NiCr-Al_2O_3 / Al_2O_3.

Table 3.
Results of nanoindentation of coatings.

Sample number	Powder name	Nanohardness, GPa	Young's modulus, GPa
1	Al_2O_3	13.54	256.13
2	Al_2O_3	14.73	261.31
3	Al_2O_3	16.42	286.12
4	NiCr	6.92	165.32
5	NiCr	8.02	176.23
6	NiCr	7.63	169.12

Figure 4 shows the SEM image of the cross section of multilayer coating on the bases of NiCr/NiCr- Al_2O_3 / Al_2O_3 . The elemental composition of the coatings was determined by using EDS analysis. From the obtained data, it can be seen that the coatings consist of a lower metal layer, an upper ceramic layer and a transitional layer of a mechanical mixture of metal and ceramics. This confirms the EDS analysis. The results of the EDS analysis are shown in Table 4.

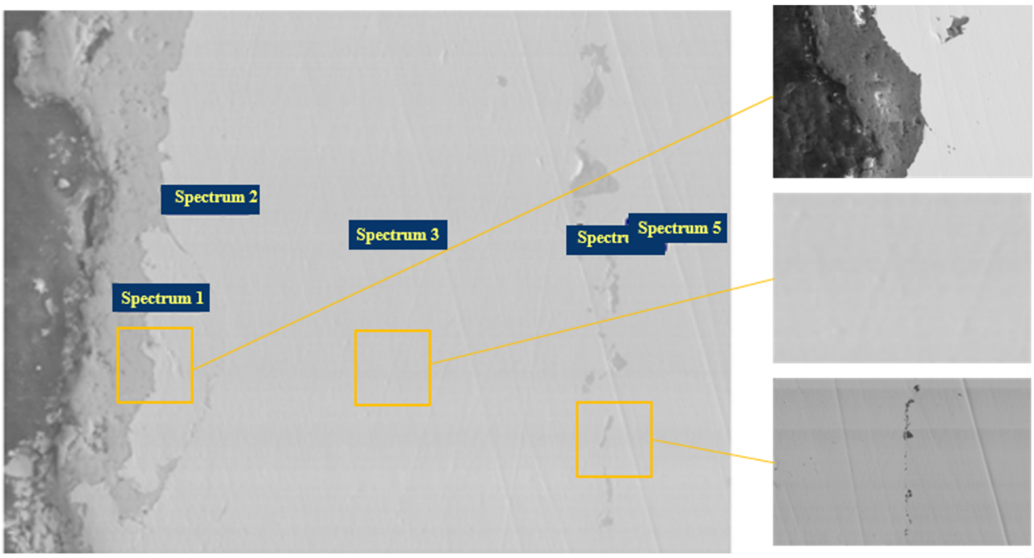

Figure 4. SEM cross-sectional image of multilayer coating on the bases of NiCr/NiCr Al_2O_3 / Al_2O_3 .

Table 4.
The results of EDS analysis.

Spectrum	Al, %	O, %	Ni, %	Cr, %	Fe, %	Total, %
Spectrum 1	39.78	31.36	13.88	14.98	0	100
Spectrum 2	29.63	26.74	24.71	18.92	0	100
Spectrum 3	19.56	17.42	39.56	23.46	0	100
Spectrum 4	7.53	4.66	49.68	38.13	0	100
Spectrum 5	1.25	1.67	23.97	15.06	58.09	10

Conclusion

On the bases of experimental obtained data and their analysis, the following conclusions were made: It was determined that the phase composition and properties of detonation coatings strongly depend on the technological parameters of spraying. When spraying powders based on Al_2O_3, the chemical and phase composition of the obtained coatings strongly depends on the degree of filling of the barrel with a gas mixture, which makes it possible to control the structure and composition of the coatings and, thus, to obtain coatings with specified properties.The method of obtaining multilayer coatings based on $NiCr/NiCr\,Al_2O_3$ / Al_2O_3 which consists of the lower metal layer, the upper ceramic layer and the transition layer of a mechanical mixture of metal and ceramics on a detonation machine was developed.The study of the elemental composition by the SEM method (EDS) showed that multilayer coating on the bases of $NiCr/NiCr\,Al_2O_3$ / Al_2O_3 has a gradient structure, as there is an increase in the concentration of ceramics from the substrate to the coating surface.

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