Structure and properties of additive products manufactured from electroerosion powders

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The paper considers the possibility of using electroerosion metal powders based on the Co-Cr alloy with different properties in additive technologies. Use of these powders opens up great opportunities for improving the technical and economic characteristics of products, and will contribute to a significant increase in their reliability, durability, weight reduction, reduction of manufacture and operation costs. The economic efficiency of the use of electroerosion cobalt-chromium powders is due to the use of waste and low energy-intensive technology for their production.
The aim of this work is studying the technology of powder fusion obtained by electroerosion dispersion of cobalt-chromium alloy waste in alcohol, on porosity, microhardness and roughness of additive products.
The process of electrodispersion, i.e. grinding of the KKhMS "Cellite" alloy (63 % Co, 27 % Cr, 5 % Mo, 2 % Ni, 2 % Fe) was carried out on an original patented installation. After dispersion of cobalt-chromium alloy waste, its destruction occurred as a result of local exposure to short-term electrical discharges between the electrodes located in the working fluid, with formation of powder particles. Butyl alcohol was used as the working fluid. The fusion of electroerosion cobalt-chromium powders was carried out by plasma on the original installation for layer-by-layer deposition, which allows varying the technological parameters of the process: the nozzle transition speed (mm/min), the distance between the nozzle and the construction zone (mm), and the fusion temperature (°C).
Based on a set of experimental studies, it was found that the melting temperature of particles of electroerosion cobalt-chromium powder practically does not effect on varying in the elemental and phase composition of samples; at the same time, with an increase of the melting temperature, the pores size and their number decrease, as well as an increase of microhardness with decrease of the height of irregularities and roughness in general are observed.
Key words: additive products, cobalt-chromium alloys, electroerosion dispersion, powder, temperature, properties.
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Introduction

Additive technologies (AT) for manufacture of products made of the materials based on metals and alloys are considered today as one of the most prospective and actively developing directions of machine-building [1-4]. Exact shape obtaining is very important, but not only one problem to be solved in the production process of the components. Such properties as elasticity, ductility, strength, wear resistance and other are also rather important. It is known that each additive process is accompanied by high-temperature effect on the billet material, what has negative influence on the above-mentioned properties [5-9]. Providing high-quality structure of the material and high level of operating properties of manufactured component is the high-priority task of additive technologies for the conditions of multiple elevation of productivity [10, 11].

Based on the technological features of use of powder particles with spheroid form and required grain size for additive installations, the technology of electroerosion dispersion (EED) is suggested. This technology is characterized by low energy capacity and ecological acceptability [12, 13]. Possibility of use of production wastes, which are more cheap in comparison with pure components, is considered as the main advantage of EED technology. Additionally, it allows to obtain powder particles from multi-component alloys.

Wide EED use for processing of metal wastes in powders with required properties and their application in the additive technologies are restricted by lack of information in the scientific and technical literature about influence of dispersed material, procedures and conditions of its manufacture on powder properties, as well as about possible areas of its practical use. In this connection, it is necessary to conduct complex theoretical and experimental researches for evaluation of possibility of powders application in AT.

The problem of improvement of products properties can be solved via use of new materials, first of all, alloyed powders. Thereby we need to examine their parameters, properties and structure in details.

Inequality of concentrations of the components in the different points of a powder body is the main disadvantage of powder products. This inequality can take place either only

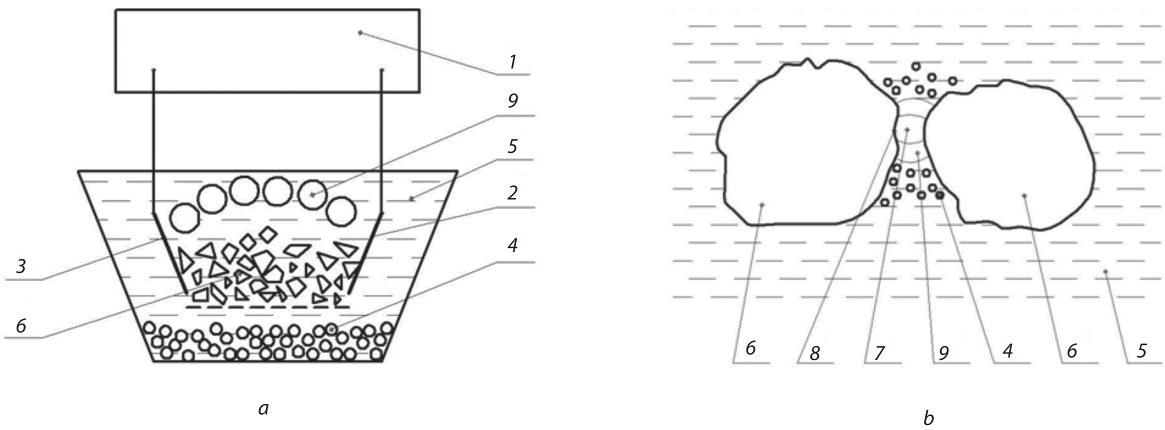

Fig. 1. The process of electroerosion dispersion for metal wastes: *a* — the scheme of installation reactor; *b* — the process route

in the initial state and on intermediate stages, or can be saved until the end of production process. Use of such materials for manufacture of wide range of components for different machine-building industries is restricted by difficulties of providing high and stable mechanical properties.

To eliminate the above-mentioned disadvantages of additive technologies, the alloyed powders, which are manufactured from wastes of metallic alloys via electroerosion dispersion, are proposed to be used. This research will support solving the problem of widening the materials range which are able for AT. The aim of this research is examination of the powder fusion technology for porosity, microhardness and roughness of additive products, while this powder is obtained via electroerosion dispersion of wastes of the cobalt-chromium alloy in alcohol.

Development of the new relationships and interactions between composition, structure and properties of additive products (from one side) and fusion technology of powder materials which are obtained via electroerosion dispersion of wastes of KKhMS alloy (from other side) is considered as the novelty of the conducted investigations.

Methods and materials

Electroerosion dispersion process (i.e. comminution) for the KKhMS "Cellite" alloy (63 % Co, 27 % Cr, 5 % Mo, 2 % Ni, 2 % Fe) was conducted using the original patented installation (RF Patent No. 2449859), see **Fig. 1**.

In the process of electroerosion dispersion of KKhMS alloy wastes, pulse voltage of pulse generator 1 was applied to electrodes *2* and *3* and then to alloy waste pieces *6* (alloy waste pieces were also use as electrodes). When the definite level of voltage was achieved, electric breakdown of working fluid *5* occurred (this fluid was located in the space between electrodes with forming of discharge channel *7*). Due to high concentration of thermal energy, material melted and evaporated in the discharge point *8*, working fluid evaporated and encircled the discharge channel with gaseous products of decomposition *9* (so-called gas bubble). As a result, essential dynamic forces developed in the discharge channel and gas bubble, drops of molten metal *4* were withdrawn out of the discharge area in working fluid encircling electrodes and then solidified in this liquid with forming spherical particles of alloyed powder.

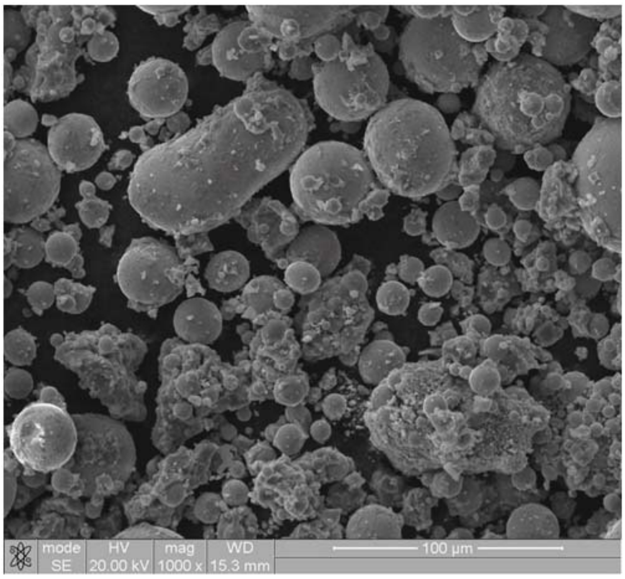

Fig. 2. Scanning electron microscope image of electroerosion cobalt-chromium powders

As a result of dispersion of cobalt-chromium alloy wasted, its destruction occurred due to local effect of short-term electric discharges between electrodes located in working fluid, with forming powder particles (**Fig. 2**). Butyl alcohol was used as working fluid.

Fusion of electroerosion cobalt-chromium powders was carried out using plasma in the original patented installation for layer-by-layer application, allowing to vary technological parameters of the process, such as speed of nozzle transition (mm/min), distance between the nozzle and construction area (mm) and fusion temperature (°C) (RF Patent No. 2750603).

The fusion temperature of particles was taken as the main and variable technological parameter of the laser sintering process during conduction of the experiments for manufacture of samples of additive products made of cobalt-chromium powder particles. Experimental samples of additive prod-

Table 1. **Results of investigation of samples porosity**

Sample	Square of analysis, μm²	Porosity, %	D_{min}, μm	D_{max}, μm	D_{med}, μm
No. 1	77217.8	1.31	0.7	10.7	0.9
No. 2	76369.6	1.25	0.1	8.6	0.3
No. 3	75310.1	0.78	0.1	5.2	0.3
No. 4	75965.0	0.29	0.1	5.0	0.3

ucts were obtained at the following temperatures: 1030 °C (No. 1), 1080 °C (No. 2), 1130 °C (No. 3), 1180 °C (No. 4).

Certification of the properties of additive products obtained of electroerosion cobalt-chromium powders was conducted using up-to-date complementary methods of physical material science.

Porosity was determined via optical inverted microscope Olympus GX51with software for quantitative image analysis. Prepared samples have not traces of grinding, polishing or pitting of structural components. Polished sections were made in the direction of cross section (fracture) of total product or its part with square at least 2 cm². The surface of polished sections of samples was ground and polished. The paper with different abrasive grain size, according to the GOST R 52381-2005 was used (R240 corresponds to grain size 50-63 μm and R600 corresponds to grain size 20-28 μm); the paper R1500 was used at the final stages.

During grinding process the samples were periodically rotated by 90°. Abrasive particles were washed out by water and subjected to polishing by a circle using metal oxides suspension (Fe_3O_4, Cr_2O_3, Al_2O_3). After achieving mirror shine, the surface of polished sections were rinsed by water, alcohol and then dried by filtering paper.

The microscope was equipped by «SIAMS Photolab» software, which was developed using the application features of the methods digital microscopy and image analysis for metallographic analysis of compounds.

Digital image of material in grey tint looks like a set of objects having close colour, brightness and morphometric signs. Respectively, automatic extraction of measuring information is connected with inevitable catching of noises and disturbances. To provide reliability of analytical results, the software has elements of expert system: operator is suggested in interactive procedure to select those automatically underlined objects which present microstructure defects, by his opinion. As soon as single pores, or chains of pores as well as micro-cracks can be detected on the controlled surface, the operator designates chains of pores with continuous marker, while single pores and micro-cracks are designated by marker as separate areas.

The results of marking are used for forming the expert conclusion and calculation of quantitative parameters of micro-damages. The results of accumulated statistical data make the base for automatic report preparation; this report includes calculated data and information about the controlled area.

The samples were tested on micro-hardness by their surface and transversal polished section using automatic system DM-8 for micro-hardness analysis via micro-Vickers method, with indentor load 200 g and 10 prints with free choice of spike point. Indentor loading time made 15 s.

Roughness of the surface layer of products was determined using automatic precise contact profilometer Surtronic 25.

The results of researches

The experimental researches were conducted earlier and they allowed to establish that fusion temperature of particles has not practical effect on variation of elementary and phase composition of the samples of additive products manufactured of electroerosion cobalt-chromium powders.

The results of investigations of samples porosity via metallographic method are presented in the **Table 1**.

Fig. 3 presents microstructure of the samples and the histogram of pores distribution according to their size.

It was established after porosity investigation of samples that the minimal porosity (0.29 %) was manifested for the sample No. 4, which was obtained at the maximal fusion temperature. At the same time, the sample No. 1, obtained at minimal temperature, was characterized by maximal porosity (1.31 %). The sample No. 4 had also minimal size of pores (5.0 μm), while the sample No. 1 had maximal size of pores (10.7 μm).

It was shown based on the conducted experimental investigations, that increase of fusion temperature of electroerosion cobalt-chromium powders leads to decrease of number and size of pores.

Microstructure of additive products, which is obtained from electroerosion cobalt-chromium powders, is characterized by fine grain building without any inclusions or discontinuities. The results of investigation of microhardness of the obtained samples are presented in the **Table 2**.

Range of variation of microhardness values for additive products, which were obtained from electroerosion cobalt-chromium powders, makes 6,55 – 13,94 MPa.

The sample No. 4, which was obtained at the maximal fusion temperature, has maximal average value of microhardness (11,12 MPa), while the sample No. 1, which was obtained at the minimal temperature, has minimal average value of microhardness (8,32 MPa), what is connected with their porosity.

The results of investigation of roughness of additive samples are presented on the **Fig. 4**.

It was established experimentally on the base of three measurements for each sample that roughness parameter Ra makes 0.73 μm, 1.25 μm, 1.52 μm and 2.14 μm for the samples No. 4, No. 3, No. 2 and No. 1 respectively.

Based on the conducted experimental investigations, it was shown that increase of fusion temperature of electroerosion cobalt-chromium powders leads to decrease of roughness of additive samples. Lowering of surface roughness is noted for porosity decrease of additive samples as well.

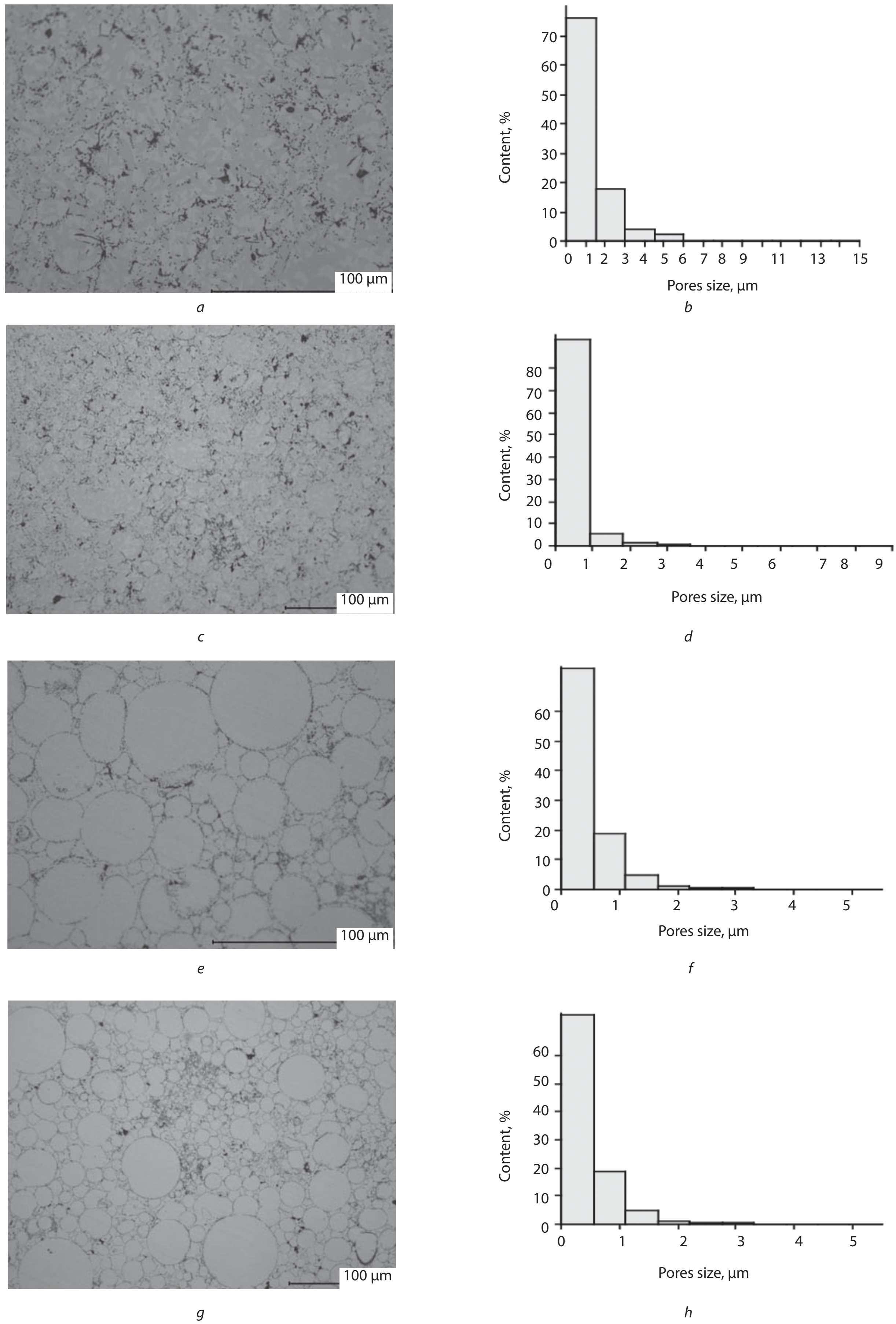

Fig. 3. Microstructure of the samples No. 1-4 (*a*, *c*, *d*, *f*) and histogram of pores distribution according to their size, the samples No. 1-4 (*b*, *d*, *f*, *h*)

Table 2. **Vickers microhardness of obtained samples**

No. of print	Fusion temperature, °C			
	1030	1080	1130	1180
1	9890	9500	9630	14170
2	8890	9760	9630	12680
3	8340	11400	10030	11740
4	8450	9760	10910	10910
5	8340	10170	13940	9250
6	7940	8240	11750	10180
7	8040	8780	10170	10760
8	7940	6550	10450	12100
9	7650	6580	13070	10460
10	7740	7650	11930	9760
Average value (measurement units)	8320	8840	11150	11200
Relative error, %	2.8	6.2	4.7	4.6

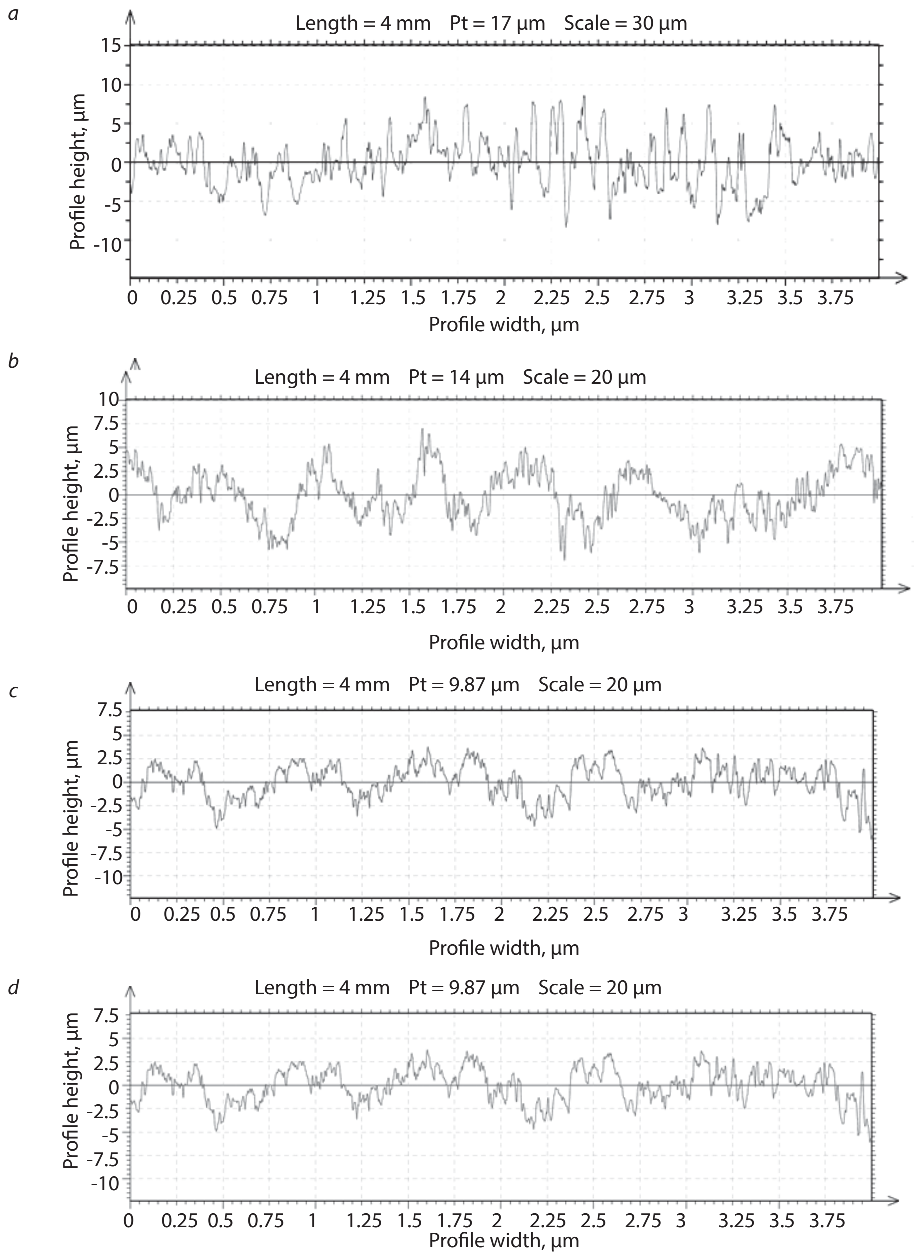

Fig. 4. Surface profilograms of additive samples No. 1 (*a*), No. 2 (*b*), No. 3 (*c*), No. 4 (*d*)

Conclusions

1. The complex of experimental investigations directed on examination of fusion temperature influence of electroerosion chromium-cobalt particles on the properties of additive products was conducted; it was finalized in the following features:

- fusion temperature of particles has no practical influence on variation of elemental and phase composition of samples. Microstructure comparison of sintered samples testified that the main structural components are similar in general, what is confirmed by the chart of elements distribution in the samples after sintering. Microstructure of additive products, which are obtained from electroerosion cobalt-chromium powders, is characterized by fine grain building without any inclusions or discontinuities;

- fusion temperature of particles has the effect on porosity variation of the samples of additive products. As a result of porosity examination, it was established that the samples obtained at fusion temperature 1180 °C have minimal porosity (0.29 % in average). But when fusion temperature decreases below 1180 °C, porosity increases and temperature elevation leads to losing of size and shape of the samples. As soon as fusion temperature of electroerosion cobalt-chromium powders rises, decrease of pores size and their number occurs.

- fusion temperature of particles influences on microhardness varying. Range of variation of microhardness values for additive products, which were obtained from electroerosion cobalt-chromium powders with one composition, makes 6.55 – 13.94 MPa, depending on temperature variation. Maximal microhardness values of the samples are achieved at the fusion temperature about 1180 °C.

- fusion temperature of particles has the effect on variation of surface roughness of additive products. As soon as fusion temperature of electroerosion cobalt-chromium powders rises, lowering of heights of surface inequalities and roughness in general takes place.

2. Electroerosion metal powders based on Co-Cr alloy, which are characterized by different properties corresponding to any operating conditions, can be prospectively used in additive technologies; it opens wide possibilities for improvement of technical and economic parameters of products and will provide substantial increase of their reliability, service life, weight lowering, cutting of manufacturing and operating expenses. Solving of these problems will help to follow the selected direction in the field of development of intelligent production technologies, new materials and engineering techniques. Economical efficiency of use of electroerosion cobalt-chromium powders is stipulated by application of wastes and energy-saving technology for their production.

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