The wear resistance additive products derived from EED cobalt powder

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Abstract. The main claim for powders for additive 3D technologies is a spherical shape of particles. Such particles are the most compact, packed in a certain volume and provide "fluidity" of the powder composition in the material supply systems with the least resistance. The wide use of the method of metal waste recycling into powders for their reuse and application in additive technologies is constrained by the lack of scientific and technical literature complete information on the impact of the original composition, modes and environment on the powder properties and practical application technologies. Therefore, comprehensive theoretical and practical researches are required to develop technologies for the reuse of electro-erosion powders and to estimate the effectiveness of their use. The aim of the work was to study the wear resistance of additive product samples, obtained from cobalt-chromium electro-erosion powder. The wear resistance of the samples was studied on a high-temperature tribometer manufactured by CCM tools. The friction coefficient (initial, maximum and average) is determined on the basis of the wear resistance assessment. The wear coefficient value of the statistical partner and the wear coefficient of the electric spark coating were also identified. The visual image of the wear trace and the wear groove profile of the electro-spark coating are shown.

1. Introduction

The technology of "three-dimensional printing" appeared in the late 80-ies of the last century. The pioneer in this field is the company 3D Systems, which designed the first commercial stereolithographic machine - SLA - Stereolithography Apparatus (1986).

The widespread use of digital technologies in the field of CAD, modeling and calculation (CAE) and machining (CAM) has stimulated the explosive nature of the development of printing technologies, and now it is extremely difficult to indicate the area of material production where to some extent printers would not have been used [1-8].

The main requirement for powders for additive 3d technologies is the spherical shape of the particles. Such particles are most compactly packed into a certain volume and ensure the "fluidity" of the powder composition in the supply systems of the material with minimal resistance. In addition, the powder should contain a minimum amount of dissolved gas. The microstructure of the powder must be uniform and finely dispersed (with a uniform distribution of phase constituents) [9, 10].

The main advantage of the technology of electroerosive dispersion (EED) is the use of waste as starting materials, which is much cheaper than the pure components used in traditional technologies. In addition, this technology allows you to obtain powders-alloys, [11, 12].

The wide use of the EED method for metal waste recycling into powders for the purpose of their reuse and application in additive technologies is helded back in the scientific and technical literature of
full-fledged information on the effect of the initial composition, regimes and media on the properties of powders and technologies of practical application. Therefore, in order to develop technologies for the reuse of electroerosive powders and to evaluate the effectiveness of their use, complex theoretical and experimental studies are needed.

The average particle size of powder obtained by EED depends upon the pulse (arc) energy, which in its turn, depends upon the voltage across the reactor electrodes (EED plant supply voltage), holding capacity of the energy discharge capacitors, sparking voltage of the working fluid, geometric parameters of the reactor (the distance between electrodes), dimensions of the dispersed material and its resistance to erosion.

To obtain powders of the required size, it is recommended to change the capacitance of the plant’s capacitors or the voltage on the electrodes. Increasing these energy parameters increases the pulse energy and the average size of the powder particles.

The aim of the work was to conduct a phase analysis of additive products from electroerosive cobalt-chrome powders.

2. Materials and methods
To carry out the planned researches, wastes of the cobalt-chromium alloy of the brand KHMS "CELLIT" were chosen. Butyl alcohol (butanol-1) was used as a working fluid. A unit for EED of conductive materials was used for the production of cobalt-chromium powders. Dispersion parameters: voltage 100 V, capacity 48 μF, repetition rate 120 Hz.

The friction coefficient and wear rate of the surface of the samples and counterbody were measured on an automated friction machine (Tribometer, CSM Instruments, Switzerland) controlled by a computer (Figure 1), according to the standard test procedure "ball-disk" (Figure 2). These tests allow using of the Hertz model; they correspond to international standards ASTM G99-959 DIN50324 and can be used to evaluate the wear resistance of the sample and the opposing member.

Figure 1. General view of an automated friction machine (Tribometer, CSM Instruments, Switzerland).
Figure 2. Standard test scheme "ball-disk", $R$ is the radius of curvature of wear; $r$ is the radius.

The samples were placed in a holder, a rod was attached perpendicular to the plane of the sample, at the end of which there was a ball with a diameter of 6 mm Al$_2$O$_3$ (aluminum oxide). By adjusting the displacement sensor, the radius of wear curvature was selected; another sensor compensated for the frictional force and allowed to know the value of the friction coefficient at a certain time.

Preparation for the test included:
A) Three types of calibration:
1) calibration motor speed and rotation; 2) calibration of the tangential displacement of the sensor; 3) the radius calibration.
B) test parameters setting with special software (Instrum X for Tribometer program). The following information required for the test was specified:
1) the frequency of the sensor interrogation; 2) data on the environment: - temperature, - humidity; 3) the load value, at which the test will be carried out, 4) the linear velocity, cm / sec; 5) mileage in meters or number of cycles; 6) information about the substrate: - coating material; - substrate material; - type of preliminary cleaning of the sample before testing; 7) information on the counter (ball): - coating material; - material of the counterbody; - type of preliminary cleaning of the counterbody before the test; - the size, mm; - geometry.

The tests were carried out in air at a load of 5 N and a linear velocity of 10 cm/sec, a curvature of the wear was 5-6 mm, friction path length was 1000 m.

According to test results, the wear resistance of the sample and the static partner (ball) was estimated from the wear factor by the formula:

$$ W = V / (P \cdot l), $$

where $W$ is the wear rate, $mm^3 \cdot N^{-1} \cdot m^{-1}$, $V$ is volume of deleted material, $mm^3$, $P$ is load, N; $l$ is friction path, m.

Having determined wear diameter of the ball with the Olympus GX 51 optical inverted microscope, the volume of the removed material on the ball was calculated by the following formula:

$$ V = \pi \cdot h^2 \cdot (r - (1/3)h), $$

where $h = r - \left(\frac{r^2 - \left[\frac{d}{2}\right]^2}{2}\right)^{\frac{3}{2}}$, $d$ is wear diameter, mm; $r$ is ball radius, mm; $h$ is segment height, mm.
The volume of the removed material was determined from the section of the wear track on the surface of the sample using an automated precision contact profilometer Surtronic 25 manufactured by Taylor Hobson. The volume of the removed sample material was determined by the formula:

\[ V = s \cdot l \]  

where \( l \) is circumference, mm; \( s \) is cross-sectional area of the wear track, mm\(^2\).

3. Results and Discussion

Visual image of the counterbody (ball) wear after multiple passes through the experimental surface of the experimental sample is shown in Figure 3.

Electron microscopic image of an additive sample after several ball passes is shown in Figure 4.

The images were obtained with the OLYMPUS GX51 inverted optical microscope, counter body was made from Al\(_2\)O\(_3\) (aluminum oxide).

The groove profile of the surface was investigated on an automated precision contact profilometer SURTRONIC 25 (Figure 5).

![Figure 3. Image of the counterbody (ball) wear after multiple passes through the investigated sample surface.](image-url)
Figure 4. Electron microscopic image of an additive sample after several ball passes.

Figure 5. Wear depth on sample surface.

Based on the results of experimental studies, the following characteristics of wear resistance were obtained: the average value of the friction coefficient 0.63; the wear factor of the static partner 0.104; the wear factor of the sample 3.37.

Based on the evaluation of the wear resistance, the friction coefficient (initial, maximum and average), the values of the wear factor of the static partner and the wear factor of the electro-spark coating were also obtained. The optical image of the wear trace and the groove profile of the wear of the electro-spark coating are shown.
4. Conclusion
According to the results of the studies of the wear resistance of additive products from electroerosive cobalt-chromium powders, it was experimentally established that the average value of the friction coefficient is about 0.673.

The conducted research allows using progressive, environmentally friendly, low-tonnage and waste-free technology of electroerosive dispersion to obtain new powder materials from waste of cobalt-chrome alloys and additive products from them with guaranteed wear resistance.

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References
[1] Wang Z, Guana K, Gaoa M. 2012 Journal of Alloys and Compounds 513 518-523.
[2] Biamino S, Penna A, Ackelid U 2011 Intermetallics. 19 776-781.
[3] Gu D D, Meiners W, Wissenbach K, Poprawe R. 2012 International Materials Reviews 57 133-164.
[4] Song B, Dong S, Zhang B 2012 Materials & Design 35 120-125.
[5] Song B, Dong S, Coddet P 2012 Surface and Coatings Technology 206 4704-4709.
[6] Wang Z, Guana K, Gaoa M 2012 Journal of Alloys and Compounds 513 518–523.
[7] Karlsson J, Snis A, Engqvist H, Lausmaa J 2013 Journal of Materials Processing Technology 213 2109-2118.
[8] Safdar A, He H Z, Wei I Y, Snis A 2012 Rapid Prototyping Journal 18 401–408.
[9] Loeber L, Biamino S, Ackelid U 2011 Solid freeform fabrication proceedings 11 547-556.
[10] Gu D D, Meiners W, Wissenbach K, Poprawe R. 2012 International Materials Reviews 57 133-164.
[11] Ageeva E V, Ageev E V, Karpenko V Yu, Osminina A S 2014 Journal of nano- and electronic physics 3 03049-1 – 03049-3.
[12] Ageeva E V, Ageev E V, Horyakova N M, Malukhov V S 2014 Journal of nano- and electronic physics 3 03011-1 - 03011-3.