DEVELOPMENT OF A MODEL FOR THE PRODUCTION OF METAL-POWDER COMPOSITIONS BASED ON CO-CR ALLOYS BY ELECTROEROSIVE DISPERSION

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Abstract. 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. The wide use of the EED method for processing metal waste into powders for the purpose of their reuse and application in additive technologies is hampered by the lack 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 required. The aim of the work was to develop a model for the production of metal powder compositions on the basis of Co-Cr alloys by electroerosive dispersion.

Based on the results of the conducted studies, it has been established that the optimum parameters for the process of obtaining powder materials by the method of electroerosive dispersion of butyl alcohol are: capacitance of discharge capacitors 48 μF, voltage on electrodes 100 V, repetition rate of pulses 120 Hz.

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 developed 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 [1-10]. 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) [1-8].

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 is powdered, which allows powder-alloys [11-13].

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1. Materials and methods

For the implementation of the planned studies, wastes of the cobaltochrome alloy of the brand KHMS "CELLIT" were chosen. As a working fluid, butyl alcohol (butanol-1) was used. For the production of cobalt-chrome powders, a unit for EED of conductive materials was used. Dispersion parameters: voltage 100 V, capacity 48 μF, repetition rate 120 Hz. The morphology of the surface of the powder obtained is shown in Fig. 1.

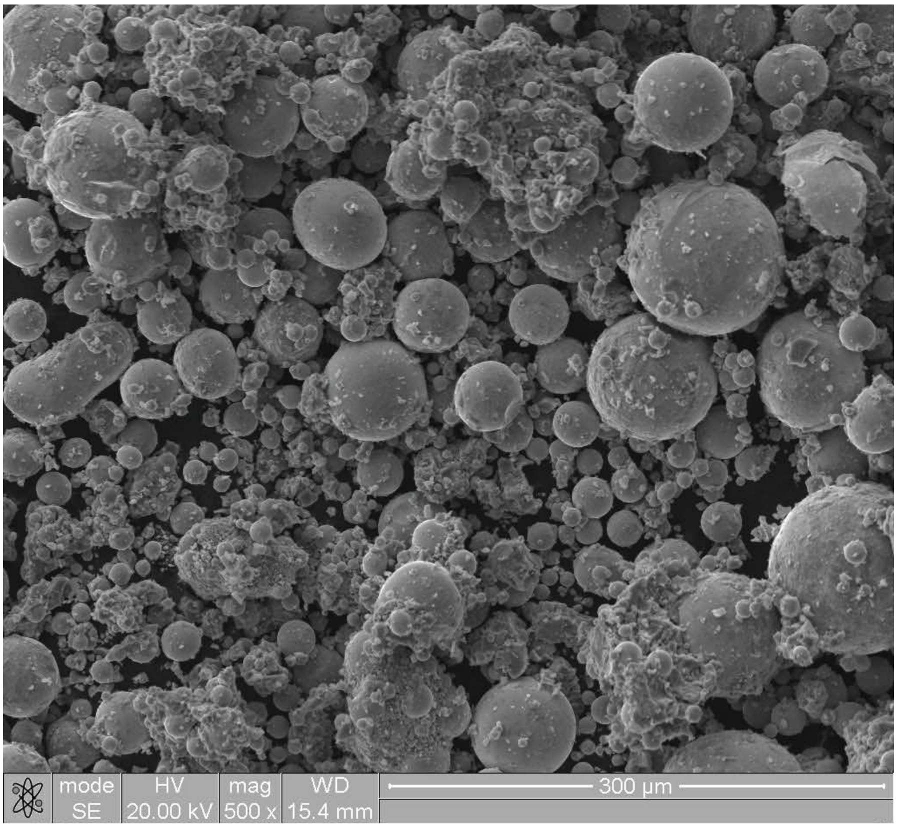

Fig. 1. A snapshot of the powder obtained in butyl alcohol

In order to meet the requirements for materials for additive technologies in terms of dimensions (average particle size of the powder material), a factor experiment was set up.

2. **Results and Discussion**

For the conduct of the factor experiment, the levels and intervals of variation of all possible factors were chosen (Table 1).

Table 1 - Levels and intervals of variation

Name	Factors		
	X_1 (C, uF)	X_2 (f, Hz)	X_3 (U, V)
Basic level	48	100	120
Variation interval	10	20	20
Top level (+)	58	120	140
Lower level (–)	38	80	100

The experimental design matrix is shown in Table 2.

Table 2 - Experimental design matrix

experiment No.	The order of experience realization	X_0 (environment)	X_1 (C, uF)	X_2 (f, Hz)	X_3 (U, V)	$X_1 X_2$	$X_2 X_3$	$X_1 X_3$	$X_1 X_2 X_3$	Y (D, µm)
1	7	+	+	+	+	+	–	–	+	33,61
2	2	+	–	+	+	+	+	–	–	30,68
3	8	+	+	–	+	–	–	+	–	24,97
4	3	+	–	–	+	+	+	+	+	28,95
5	1	+	+	+	–	+	+	+	–	31,59
6	4	+	–	+	–	–	–	+	+	26,58

7	5	+	+	–	–	–	+	–	+	27,09
8	6	+	–	–	–	+	–	–	–	27,93

To determine the variance of the optimization parameter, 3 experiments were conducted to determine the factors at the main levels. Certain values of the optimization parameter y_u, its average value of ý, deviations of the optimization parameter values from its mean value (yu-ý) and the squares of their deviations are given in Table 5.3.

Table 3 - Auxiliary table for calculating

experiment No.	y_u	ý	$(y_u – ý)$	$(y_u – ý)^2$
1	27,29		0	0
2	27,09		+0,2	0,04
3	26,89		-0,2	0,04
$\Sigma(y_u – ý)^2$				0,08

Variance of the optimization parameter:

$$S_Y^2 = \frac{1}{3-1}\sum_{n-1}^{3}(y_U - y)^2 \qquad (1)$$

Next, we obtain the coefficients of the model:

$$b_0 = \frac{1}{N}\sum_{j=1}^{N} y_j \qquad (2)$$

$$b_i = \frac{1}{N}\sum_{j=1}^{N} x_{ij} y_i\ . \qquad (3)$$

$$b_{ij} = \frac{1}{N}\sum_{j=1}^{N} x_{ij} x_{ij} y_i \qquad (4)$$

b_0=3,39; b_1=10,17; b_2=20,34; b_3=40,68.

The average quadratic error in determining the regression coefficients:

$S\{b_i\} = (Sy / N)^{1/2}$. (5)

$S\{b_i\} = (S^2y / 8)^{1/2} = 0,07$.

Confidence interval of regression coefficients with the number of degrees of freedom f=2:

$\Delta b = \pm t\cdot S\{b_i\}$. (6)

$\Delta b = \pm 4,3\cdot 0,07 = \pm 0,3$.

All without exception, the regression coefficients according to the absolute value of the more confidence interval, for this reason they can be assumed to be statistically important. Thus, we have obtained a model in the form of a polynomial of the first degree:

$$Y = 3,39 + 10,17\cdot X_1 + 20,34\cdot X_2 + 40,68\cdot X_3.$$

According to the model obtained, the optimization parameter increases with increasing values of the factors X_1, X_2 and X_3. Moreover, the greatest influence is exerted by parameter X_3, i.e. voltage on the electrodes.

The adequacy of the model was checked according to the F-criterion of Fisher. For the purpose of calculating the variance of adequacy, an additional table 4 was compiled.

Table 4 - Auxiliary table for calculating S_{ad}^2

experiment No.	y_j	$\hat{y}_j$	$y_j – \hat{y}_j$	$(y_j – \hat{y}_j)^2$
1	31,59	31,32	0,27	0,0729
2	30,68	30,85	-0,17	0,0289
3	28,95	29,11	-0,16	0,0256
4	26,58	26,15	0,43	0,1849
5	27,09	27,29	-0,2	0,0400

6	26,58	26,45	0,13	0,0169
7	33,61	33,43	0,18	0,0324
8	24,97	24,74	0,2	0,0400
$\sum(y_j - \hat{y}_j)^2$				0,4416

$S_{ad}^2 = (y_j - \hat{y}_j)^2 / (N - (k+1))$. (7)

$S_{ad}^2 = 0{,}4416 / (8 - (3+1)) = 0{,}11$.

$F_p = S_{ad}^2 / S_y^2 = 0{,}11 / 0{,}04 = 2{,}75$.

The tabular value of the F_t-criterion at the 5% significance level and the degrees of freedom for the numerator 4 and for the denominator 2 is 19,3. $F_p < F_t$. Consequently, the model is adequate.

The resulting equation was used for steep ascent along the response surface. A steep ascent started from the zero point (main levels): X_1 = 48 μF, X_2 = 100 Hz, X_3 = 80 V (Table 5.5). The motion step for factor X_1 was taken equal to 5 μF. The motion step was calculated for X_2 = 10,3, X_3 = 9,8.

Table 5 - Calculation of steep ascent

Name	X_1 (C, uF)	X_2 (f, Hz)	X_3 (U, V)	Y
Basic level	48	100	120	–
Coefficient b_i	13,4	13,8	73,3	–
Variation interval ξ_i	10	20	20	–
$b_i \cdot \xi_i$	134	276	1466	–
Step Δ_i	5	10,3	9,8	–
Rounded step	5	10	10	–
Mental experience	38	60	60	–
Mental experience	43	80	80	–
Realized experience 9	48	120	100	27,09
Mental experience	53	120	120	–
Realized experience 10	58	140	140	33,61

3. Conclusion

According to the series of experiments, the limiting value of the optimization parameter Y was adopted, which was 27,09 μm. Thus, the optimal parameters for the process of obtaining powder materials by the method of electroerosive dispersion of butyl alcohol are: capacitance of discharge capacitors 48 μF, voltage at electrodes 100 V, repetition rate 120 Hz.

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