Problems of Tribology, V. 29, No 1/111-2024, 45-52

Problems of Tribology
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DOI: https://doi.org/10.31891/2079-1372-2024-111-1-45-52

Optimization of technological parameters at discrete strengthening of steel cylindrical surfaces

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Received: 31 January 2024: Revised 25 February 2024: Accept 12 March 2024

Abstract

The technologies of continuous strengthening of technological surfaces have practically exhausted their capabilities, which calls for the creation of fundamentally new approaches. The application of the principles of discrete-oriented strengthening of tribosystems has wide prospects for improving existing methods of strengthening due to the selection of modes and control of the geometric structure of the surface layer. The essence of the discrete-oriented strengthening method is the application of combined electromechanical processing and electrocontact cementation of cylindrical surfaces. The purpose of the work is to determine the parameters of discrete processing of cylindrical steel parts that are optimal according to the surface hardness criterion. Using the Statistica program, a factorial experiment was implemented according to the Box-Behnken plan, and the results of dispersion and regression analysis of the influence of processing parameters on microhardness were obtained. It was established that the following optimal parameters of DOZ processing are necessary to achieve the maximum values of microhardness (5950 MPa): current strength-500A, force-350 N, contact time-0.3 s.

Key words: strengthening, surface, hardness, technological parameters, optimization, Statistica

Introduction

Widely used technologies of continuous strengthening of technological surfaces have practically exhausted their capabilities, which calls for the creation of fundamentally new approaches. The application of the principles of discrete-oriented strengthening of tribosystems has broad prospects for improving existing approaches due to the choice of strengthening technology and the principles of the geometric arrangement of strengthening islands. Bearing tribosystems are one of the most common types of friction nodes, which are an integral and responsible component of modern machines: bearings, axles, shafts, bushings of technological and transport machines. When analyzing the performance of bearing tribosystems, an algorithm for assessing the impact of technological and design factors on their wear resistance and durability is necessary.

Literature review

Much attention is paid to the problem of creating discretely reinforced surfaces in modern scientific literature. In [1], a study of the properties and characteristics of the surfaces of a discrete structure with mechanically formed depressions was carried out. In work [2] a mathematical model of discrete frictional contact of bodies with periodic surface textures is proposed. The contact problem is reduced to a system of singular integral equations for the functions of the heights of the contact gaps and the relative displacement of the surfaces in the sliding zones. Characteristics of contact deformation and wear of materials with a smooth and discrete track were investigated using nanoindexing and nanoscratching [3]. Wear tests have shown that wear is less for discrete discs than for smooth discs.

Research [4] determined the effect of discrete point laser hardening on abrasion and contact fatigue resistance during rolling. Samples hardened with adjacent and separated laser spots showed higher abrasion resistance than surfaces treated with overlapping laser spots.

In order to improve the surface tribological properties of titanium alloy, laser processing technology was used in [5] to obtain a cellular texture on the surface of the material. Surface textures of grooves with different orientation and distance between them were obtained on the Ti–6Al–4V alloy using a laser in the study [6].

In contrast to traditional research and development of new materials and coatings, three types of surface microstructure, including V-shaped, U-shaped and ring-shaped groove microstructures, were performed in [7] to increase the erosion resistance of sludge. In [8], a groove of a certain size was made, then it was filled with pure phenolic resin and molybdenum sulfide additives to obtain a surface with time-varying contact characteristics. Operational characteristics of friction pairs of a cylinder liner - piston ring of a diesel engine with different surface textures were studied in [9].

Therefore, the problem of creating discrete structures on the surfaces of materials and researching the technological parameters of their formation is an urgent task.

The essence of the process of discrete strengthening of cylindrical parts.

The essence of the discrete-oriented strengthening method is the application of combined electromechanical processing and electrocontact cementation of cylindrical surfaces using a carbide roller as a tool. The schematic diagram of DOZ is shown in fig. 1.

The working tool-roller 4 is pressed against the processed workpiece with a given spring force in the range of 100...500 N. One current pole from the power transformer is supplied to the workpiece through the contact roller. The second pole is brought to the processed workpiece. At the same time, an electric discharge occurs between the roller and the tool, which leads to local heating of the contact point. Due to heating, structural transformations similar to the hardening process occur in the surface layers of the metal with the formation of a so-called white layer. Additionally, during processing, the outer surface of the shaft is covered with a layer of graphite by rubbing it with a graphite rod. Graphite, falling into the place of contact between the tool and the workpiece, is also heated and can diffuse into the surface under the action of contact pressure from the roller. That is, there is a local high-temperature diffusion of carbon into the surface of the workpiece, that is, the process of cementation.

The roller and cylinder are set by the shaping movements inherent in the usual processing on a lathe. By setting the movement-feed step, it is possible to form specified processing tracks on the surface of the workpiece.When a large amount of Joule heat is released, the surface of the microvolume is rapidly heated (1000C/s) with its plastic deformation.

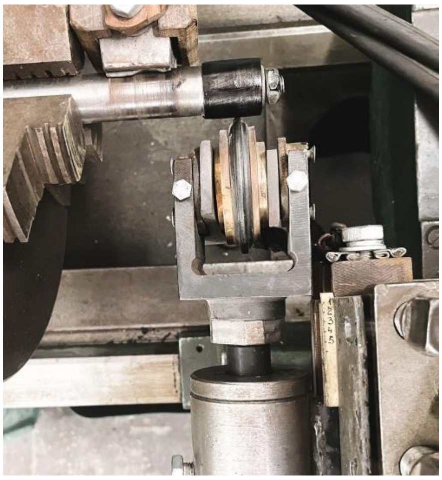


Fig. 1. Schematic diagram of the discrete-oriented method of strengthening cylindrical surfaces

Then intense cooling takes place due to heat dissipation inside the material. As a result, a finely dispersed and hard martensitic "white layer" structure with high strength and wear resistance is formed in the surface layer.

The installation allows strengthening of various cylindrical parts, including the bearing necks of the camshaft of the internal combustion engine. To apply the graphite layer on the surface of the workpiece, cylindrical graphite rods with a diameter of 10 mm were used. Samples made of 20X steel were mounted on a cylindrical mandrel, which rested on the conical center of the installation. In the process of rolling with a roller on the surface of the samples, strengthened strips were formed with a step in accordance with the given feed of the movement of the roller (1.5...2 mm).

Optimization of technological parameters of the discrete-oriented method of strengthening bearing tribosystems

The software package for statistical analysis STATISTICA was used to plan the experiment to determine the optimal values of the technological factors of the electrical contact strengthening process. The STATISTICA DOE package module is intended for experiment planning.

The 3-level Box-Behnken plan was used for planning. In statistics, Box–Behnken plots are experimental plots for response surface methodology developed by George E.P. Boxing. Each factor or independent variable is assigned one of three equidistant values, usually coded as -1, 0, +1. (At least three levels are required to achieve the next goal.) The plan should be sufficient to fit a quadratic model, that is, a model containing elements in a square, product of two factors, linear. The ratio of the number of experimental points to the number of coefficients in the quadratic model must be justified (in fact, their plans are kept in the range from 1.5 to 2.6). The variance of the estimate should depend only on the distance from the center of the plan.

The STATISTICA DOE module contains a complete implementation of standard (block) 3**(kp) plans. The module also includes standard Box-Behnken plans. As with other plans, it is possible to display and save these plans in standard or random order, request replicas or individual experiments, view the plan and block generators, and more. The program performs a complete analysis of 3**(kp) plans. It is possible to include any effects in the analysis. Main effects are broken down into linear and quadratic effects, and interactions are broken down into linear-linear, linear-quadratic, quadratic-linear, and quadratic-quadratic effects. You can view correlation matrices of factors and effects. The program calculates standard estimates of variance analysis parameters (standard errors, confidence intervals, statistical significance, etc.), coefficients for recoded (-1, 0, +1) factors and coefficients for untransformed factors. The analysis of variance table will contain tests for the linear and quadratic components of each effect and combined tests for effects with many degrees of freedom. If the design contains replicates, the net error estimate can be used for analysis of variance and significance testing; in this case, a general loss of consent test will also be conducted. To interpret the results, the program calculates a table of means (and confidence intervals), as well as marginal means (and confidence intervals) for the interactions. Graphical options include plots of means and marginal means (with confidence intervals), Pareto effects plots, normal and semi-normal probability effect plots, response surface plots, and contour plots.

On the Pareto diagram of the effects, the estimates of the effects of the analysis of variance are arranged by the absolute magnitude of the values: from the largest to the smallest. The magnitude of each effect is represented by a bar, and the bars are crossed by a line indicating how large the effect must be (ie, how long the bar must be) to be statistically significant. It has been established that the main technological parameters affecting the parameters of hardening at DOZ are: the amount of operating current of the power source, the force of pressing the working roller against the surface of the shaft, and the duration of contact between the tool and the processed part. The duration of contact depends on the speed of rotation of the cylindrical part and the size of the contact area, which was estimated when setting the contact parameters. In order to evaluate the influence of the specified factors and determine their optimal values according to the criterion of ensuring maximum hardness, it is advisable to use the methodology of planning the experiment, with the accepted ranges:

Factor	Current strength, A	Effort, N	Contact time, p
min	200	200	0.1
max	800	500	0.3
average	500	350	0.5

In this case, taking into account the planning of the experiment to determine the optimal values of the technological factors of the electrical contact strengthening process, the software package for statistical analysis STATISTICA was used. Taking into account the number of factors and their independent influence on the response function, the 3-level Box-Behnken plan was used for planning:

No. of the experiment	Current strength, A	Effort, N	Contact time, p
1	-1	0	-1
2	-1	-1	0
3	+1	-1	0
4	+1	0	+1
5	0	+1	-1
6	0	0	0
7	0	0	0
8	-1	0	+1
9	+1	0	-1
10	+1	+1	0
11	+1	-1	+1
12	-1	+1	0
13	+1	+1	+1
14	+1	-1	-1
15	+1	0	0

Using the program menu, an experiment plan was formed, which consists of 15 experiments, presented in table 3.1.

Table 1.

Factorial experiment plan for the DOZ method

No. of the experiment	Current strength, A	Effort, N	Contact time, p	Microhardness, MPa
1	200	350	0.1	4500
2	200	200	0.3	4400
3	800	200	0.3	4900
4	800	350	0.5	5300
5	500	500	0.1	6050
6	500	350	0.3	5800
7	500	350	0.3	6150
8	200	350	0.5	4750
9	800	350	0.1	5000
10	800	500	0.3	5750
11	500	200	0.5	6300
12	200	500	0.3	5250
13	500	500	0.5	6400
14	500	200	0.1	5750
15	500	350	0.3	5900

Microhardness was taken as the response function. Next, the Statistica program allows you to perform a variance analysis to determine the effect of processing parameters on the response function. To assess the significance of the factors, a Pareto map was constructed, shown in Fig. 2.

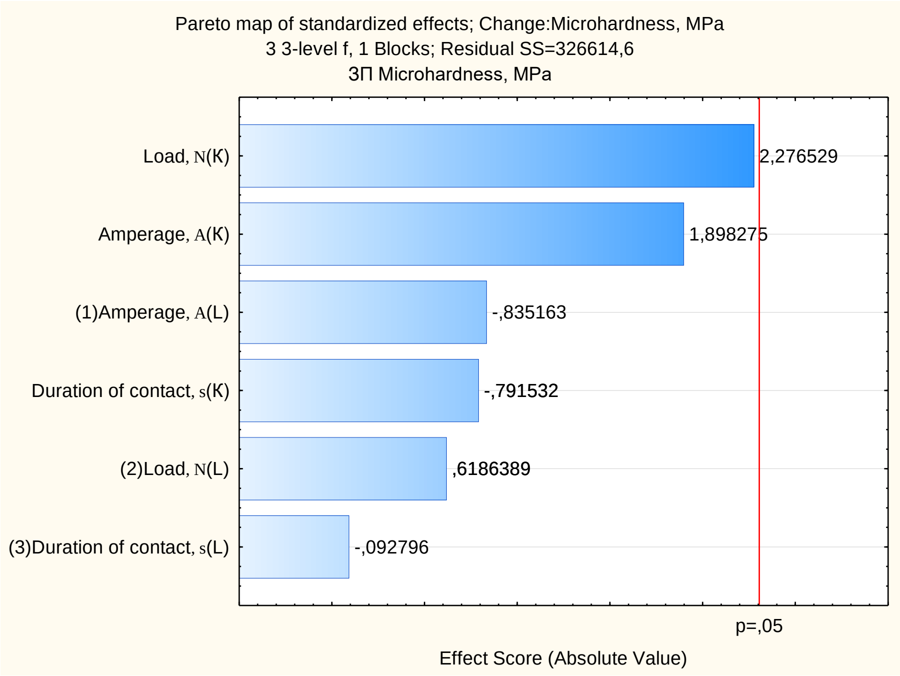


Fig. 2. Pareto map of the importance of operating factors

On the diagram, the letter L indicates the linear effect of the factor, and the letter K indicates the effect of the factor value in the quadratic equivalent. From the analysis of the diagram, it can be seen that the quadratic value of the current and the linear value of the pressing force have the greatest influence on the microhardness, the contact time has a smaller influence, and the squares of the force and the contact time in the response functions can generally be neglected, since they are beyond the red limit of significance.

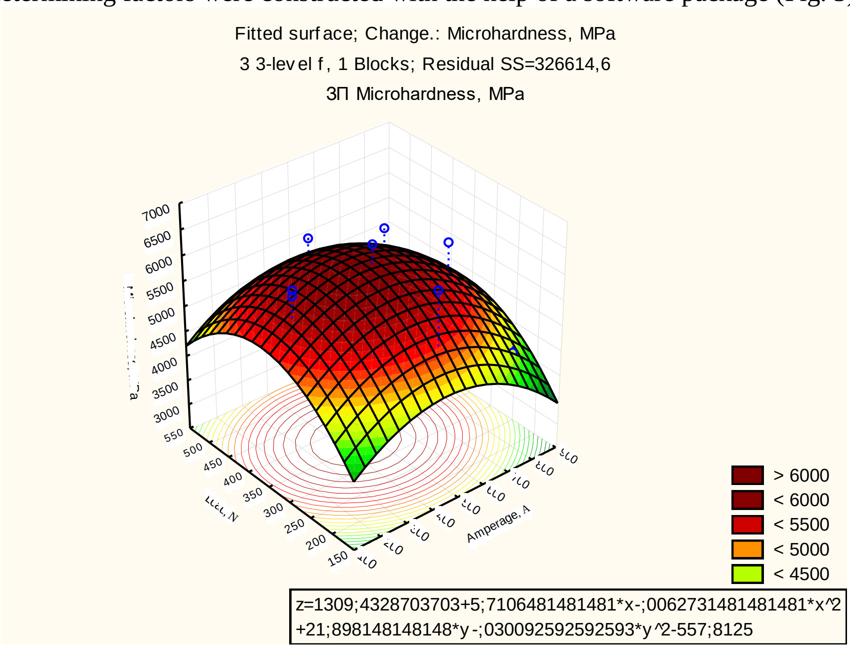
The results of variance analysis are presented in Table 2.

Table 2

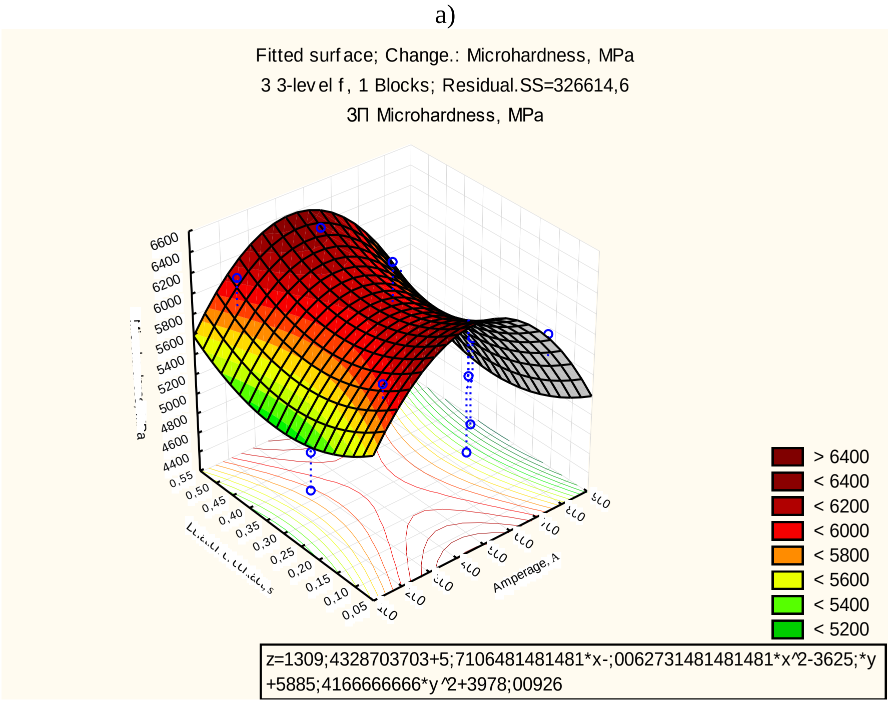
Results of dispersion analysis

Factor	Analysis of variance; Prm.: Microhardness, MPa; R-squared=.94983; Rate.9122 (3 fact. Box-Behnken plan (Data table 1) in Plan_7n.stw) 3 3-level f, 1 Blocks; Final.SS=37812.5 ZP Microhardness, MPa				
	SS	ss	MS	F	p
(1) Current strength, A(L)	525313	1	525313	13.8926	0.005810
Current strength, A(K)	4119375	1	4119375	108.9421	0.000006
(2) Effort, H(L)	551250	1	551250	14.5785	0.005103
Effort, N(K)	121298	1	121298	3.2079	0.111060
(3) Contact time, s(L)	262812	1	262812	6.9504	0.029882
Contact time, s(K)	144	1	144	0.0038	0.952269

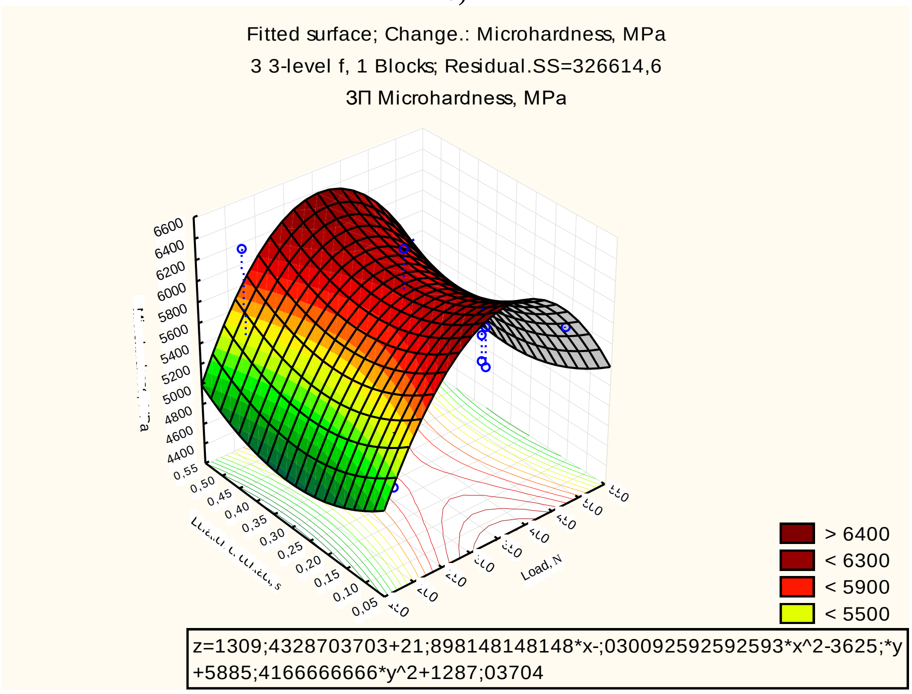
In the table, the value of Fisher's test is indicated by the letter F, and the Student's probability test by the letter p. The results shows the adequacy parameters of the built experiment plan, that is, in general, the obtained experiment plan can be considered adequate. Next, graphs of response functions for microhardness from a combination of determining factors were constructed with the help of a software package (Fig. 3).



a)



b)



c)

Fig. 3. Graphs of response functions and approximating correlation functions

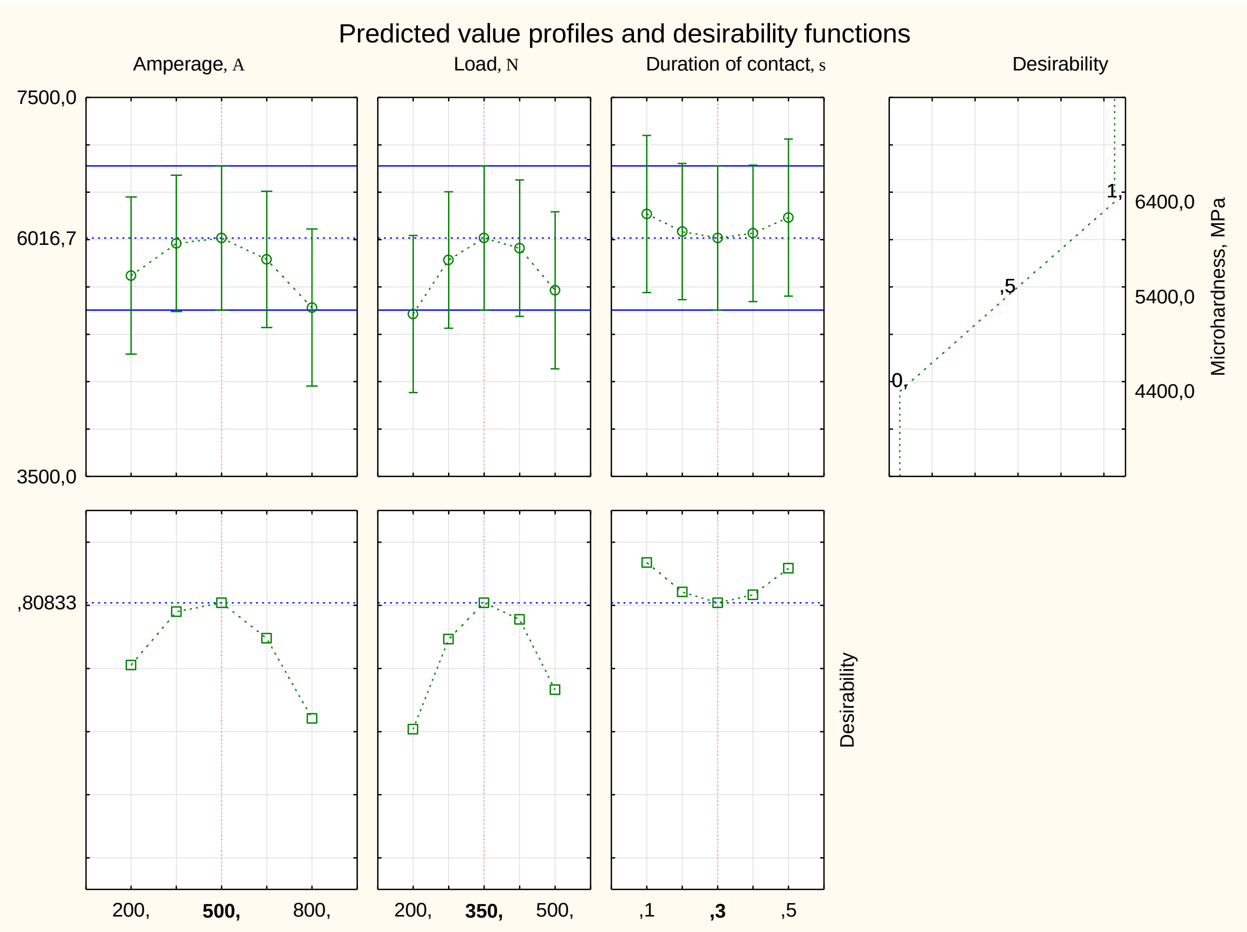


Fig. 4. The value of desirability indicators for the maximum value of the response function (microhardness)

So, it follows from the results that to achieve the maximum values of microhardness (5950 MPa), the following optimal parameters of DOZ processing are necessary: current strength - 500A, force - 350 N, contact time - 0.3 s.

Analysis of the obtained graphs shows that the current strength has a clearly defined extreme influence on the microhardness, while the influence of other factors is almost linear.

The results of the regression analysis, that is, the determination of the coefficients of the regression equations, are shown in Table 3.3.

Table 3

Results of regression analysis

Factor	Regression; R-squared=.94983; Rate.9122 (3 fact. Box-Behnken plan (Data table 1) in Plan_7n.stw) 3 3-level f, 1 Blocks; Final.SS=37812.5 ZP Microhardness, MPa					
	Regression. Coef.	St. Osh.	t(8)	p	-95.% Dov. Pred	+95.% Dov. Pred
Average/St. Member	2677,257	646,147	4.1434	0.003238	1187.24	4167.275
(1) Current strength, A(L)	12,590	1,148	10.9716	0.000004	9.94	15,236
Current strength, A(K)	-0.012	0.001	-10.4375	0.000006	-0.01	-0.009
(2) Effort, H(L)	-3,889	3,182	-1.2223	0.256372	-11.23	3,448
Effort, N(K)	0.008	0.004	1.7911	0.111060	-0.00	0.018
(3) Contact time, s(L)	1000,000	1556,394	0.6425	0.538515	-2589.05	4589.052
Contact time, s(K)	-156,250	2529,931	-0.0618	0.952269	-5990.28	5677,782

To determine the optimal values of the determining factors of the processing process, a spline approximation of the plan results was carried out using the discrete method according to the criterion of maximum microhardness. In fig. 4 are given by the results of such approximation.

Conclusions

In order to determine the optimal technological parameters of the discrete-oriented method of strengthening with the help of the Statistica program, a factorial experiment according to the Box-Behnken plan was implemented, and the results of dispersion and regression analysis of the influence of processing parameters on microhardness were obtained. It was established that the following optimal parameters of DOZ processing are necessary to achieve the maximum values of microhardness (5950 MPa): current strength-500A, force-350 N, contact time-0.3 s.

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Диха О.В., Дитинюк В.О., Грипинська Н.В., Вичавка А.А. Оптимізація технологічних параметрів дискретного зміцнення сталевих циліндричних поверхонь

Технології суцільного зміцнення технологічних поверхонь практично вичерпали свої можливості, що викликає потребу у створення принципово нових підходів. Застосування принципів дискретно-орієнтованого зміцнення трибосистем має широкі перспективи для вдосконалення існуючих способів зміцнення за рахунок вибору режимів та керування геометричною будовою поверхневого шару. Сутність дискретно-орієнтованого методу зміцнення полягає у застосуванні комбінованої електромеханічної обробки і електроконтактної цементації циліндричних поверхонь. Метою роботи є визначення оптимальних за критерієм поверхневої твердості параметрів дискретної обробки циліндричних сталевих деталей. За допомогою програми Statistica реалізований факторний експеримент за планом Бокса-Бенкена, отримані результати дисперсійного і регресійного аналізу впливу параметрів обробки на мікротвердість. Встановлено, що для досягнення максимальних значень мікротвердості (5950 МПа) необхідні наступні оптимальні параметри обробки ДОЗ: сила струму-500А, зусилля-350 Н, час контакту-0,3 с.

Ключьові слова: зміцнення, поверхня, твердість, технологічні параметри, оптимізація, Statistica