

Determination of regression materials microhardness, processed by low-temperature plasma dependence on process conditions

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Abstract. The influence of conditions of plasma surface treatment on hardening of carbon steel technological process was analyzed. Hardening was carried out in plasma electrothermal line with an electrolytic cathode. When processing, steel crystal grains are crushed and the structure is changed from ferrite-pearlite to bainite- troostite and martensite, depending on the processing conditions. In this case the surface microhardness increase in 2 - 3 times. The dependence of the carbon steel surface microhardness on the discharge current (2 - 10 A), the distance between the heat source and the surface, the plasma gas flow rate and treatment duration was found. On the basis of multifactor experiment planning methods and the method of least squares, the formula that describes this relationship was found. This allowed to conduct a targeted search of optimal conditions of processes of hardening steel and improve the efficiency and quality of research.

1. Introduction

Looking for ways to modify the properties of materials - this is one of the main ways of materials development. Thus methods for surface treatment are preferred, since in most cases, the characteristics of surface determine the level of material properties overall. In addition, surface modification is more attractive in relation to methods of changing the bulk characteristics of the materials and products from an economic point of view. All this has led to the rapid development of research and development aimed at improving the existing and creation of new methods of impact on the surface in order to give it the required characteristics of the operation conditions.

Methods for surface modification are divided into two groups: the modification and coating deposition with a change of state, structure, surface properties [1-6]. This approach allows the effective use of the combination of the properties of the base material and a modified surface layer, a surface modification processes can be quite easily integrated into the process of production or repair products.

All the more prominent place in modern technology is occupied by the methods of hardening materials by highly concentrated radiation sources using plasma torches. The advantages of these techniques are: the high technological flexibility, independence from the mechanical strength of the processed materials, the possibility of an effective mechanization and automation of technological processes.

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2. Statement of the problem

One of the tasks that you want to optimize the plasma technology process is the selection of the most favorable ratios of the numerous factors that influence the final result, such as the energy potential of the plasma jet, the distance from the source to the surface to be treated, plasma gas flow, processing time, etc. The systematic study of the influence of each individual factor leads to unnecessarily high losses of time and money.

The objective of this work is to determine the regression dependence of the strength characteristics of the materials processed by the process conditions.

3. Research method

To harden the surface of metals the plasma electrothermal line [7] with an electrolytic cathode (Figure 1) was used. Obtaining plasma using pairs of "metal-electrolyte" [8-10] is much more favorable than pairs of "metal-metal" because electrolytes are cheap and based on their manufacturing processes are environmentally friendly, and surfaces made from them have a very good quality [11]. This method of construction hardening steels allows to obtain a layer with high physical-mechanical characteristics, therefore, significantly increase the service life of parts.

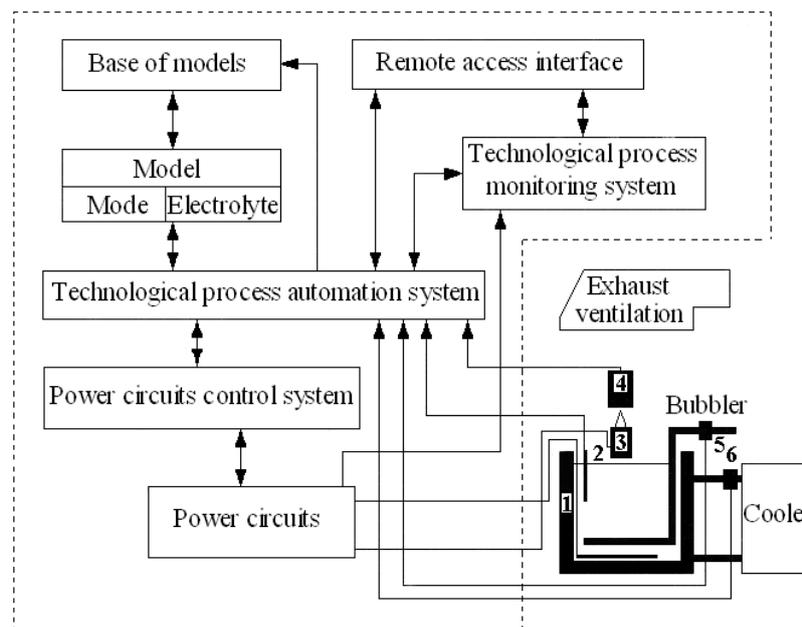


Figure 1. A generalized block diagram of a plasma processing electrothermal line (1 – electrolytic cell; 2 – electrolyte temperature sensor; 3 – head of plasma electrothermal line; 4 – workpiece; 5 – air flow sensor; 6 – water pressure sensor in the electrolytic cell cooling system).

In order to optimize plasma hardening process we need to determine product regression dependence of the hardened layer hardness on some of the input parameters [12]. To do this, we use multifactor experiment planning method. Application of multifactor experiment planning methods allows to minimize experimental efforts, improves the efficiency and quality of research, allows a targeted search for optimal flow conditions of metal hardening processes. Since all of the input parameters considered in the study is not possible to be selected, setting and hardening process were selected as the most significant parameters: discharge current (I), the distance from the heat source to the metal surface (h), plasma gas flow (Q), and the processing time (τ). As the output value (y) the

parameter optimization HV (metal hardness) was selected. The lower and upper levels of the factors, as well as the range of variation of their values are given in Table 1.

Table 1. Levels and intervals of varying factors.

Factors	τ, c	$Q, m^3/c \cdot 10^{-5}$	h, m	I, A
Main level	3.5	31.5	0.0725	6
Interval of varying	1.5	12.2	0.0325	4
Upper level	5.0	43.6	0.1050	10
Lower level	2.0	19.3	0.0400	2
Code	x_1	x_2	x_3	x_4

4. Results and discussion

The mathematical processing of the experimental results by the method of least squares [13, 14] and MathCad software package yielded a regression equation for steel grade 40, as follows:

$$y=387,4+25,4 x_1+46,5x_2+58x_3+38,6 x_4+47,3 x_1x_2+35,1x_1x_3-10,3 x_2x_3$$

Samples were analyzed for the distribution of microhardness and microstructure. As a result, it found that treatment significantly alters the microstructure of the steel. Thus, when a combination of factors x_1 - x_4 to the surface treatment of parts composed of ferrite and pearlite in a grid along the grain boundaries of pearlite, and thereafter, recrystallization occurs on the surface layer to a depth of 0.6 mm. Grid ferrite was broken and the metal start to be consisted of bainite and troostite. As a result the initial sample microhardness was 240HV, after treatment of 520HV.

In another combination the hardened layer with the structure of martensite and troostomartensita of different dispersion was formed on material surface. In this case the crystal grains are milled, microhardness as compared with the original structure of the sample to a depth of 0.5-1.5 mm on average increased by 3 times. It was getting larger as getting closer to the center of the plasma jet, longer processing time and discharge capacity (Figure 2).

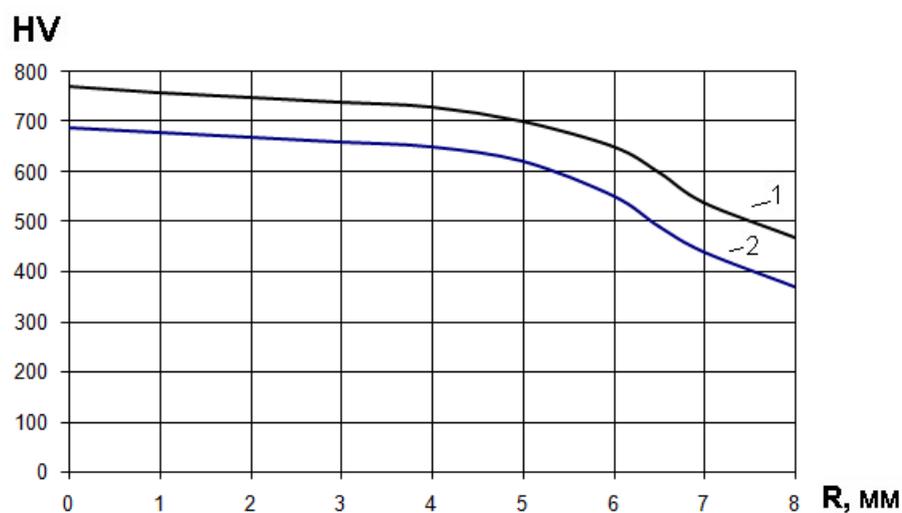


Figure 5. Dependence of the microhardness of steel 40 at a distance R from the center of the plasma jet on the processing time, the distance from the surface of the product to the device and discharge power (1 – $t = 10 c$, $l = 5 mm$, $N = 10 kW$; 2 – $t = 8 c$, $l = 7 mm$, $N = 8 kW$).

The adequacy of the model was tested using a F-test [15]. The error mean square

$$\sigma^2(y) = \frac{1}{N(n-1)} \left[\sum_{i=1}^N \sum_{j=1}^n (y_{ij} - \bar{y}_i)^2 \right]$$

and adequacy dispersion were determined

$$\sigma_{ag}^2 = \frac{1}{F_{ag}} \left[\sum_{i=1}^N n(\bar{y}_i - y_{im})^2 \right]$$

where $n = 3$ is the number of repeat experiments at each point of the space factor; $N = 8$ is the number of different experiments; $y_i = \frac{1}{n} \sum_{j=1}^n y_{ij}$ - the average real value of the response in the i -th point of the factor space; y_{ij} - response value in a single experiment; y_{im} - response value predicted in the i -th experiment on the received model; F_{ag} - number of degrees of freedom.

It has been proposed that the ratio $F = \sigma_{ag}^2 / \sigma^2(y)$ does not exceed the tabulated value of F-test at a significance level $\alpha = 0,05$. Thus, the adopted model can be considered adequate.

Testing of the significance of individual regression coefficients was performed by Student's t -distribution: parameter was calculated

$$t_k = \frac{a_k}{\sigma^2(a_k)}$$

(где $\sigma^2(a_k) = \frac{\sigma^2(y)}{N}$),

which equalized with a table at a significance level $\alpha = 0,05$. The coefficients for which $t_k > t_{table}$, were considered as minor.

Taking into account the procedures described the regression equation took the following form:

$$y = 387,4 + 25,4 x_1 + 46,5 x_2 + 58 x_3 + 38,6 x_4 + 47,3 x_1 x_2 + 35,1 x_1 x_3$$

5. Conclusion

The formula that describes the impact of the discharge current, the distance between the heat source and the surface to be treated, the plasma gas flow rate and duration of exposure to the plasma on the hardness of the surface of materials treated with plasma electrolytic cathode was found. The dependence found can be used to determine the optimal process conditions of plasma treatment.

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