Multiple-factor model of hardness of steel 40H13 after laser processing

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Abstract. The multiple-factor experiment is planned and made, and the hardness of the chromic steel 40H13, which is subjected to laser processing on a multibeam laser complex, is determined. Samples in the form of a cylinder 7 mm long and with a diameter of 30 mm are exposed to laser processing. Hardness of the processed surface layer of samples was measured by means of the Micro-Combi Tester installation of CSM Instruments (Switzerland). The independent entrance factors of process, which significantly impact on operational indicators of the processed surface layer, are chosen: power of laser radiation, longitudinal feed of laser beam and a distance from protective glass of a focusing head up to the processed surface. As a result of performance of the plan of a multiple-factor experiment and statistical data processing of a planning matrix the regression equations, which connect the optimization parameter with independent factors, having the interactive and dominating impact on formation of physic-mechanical characteristics of quality of the processed surface layer are received. On the basis of the received multiple-factor model and its graphic interpretation the appointment and optimization of modes of the laser processing, which provides the required values of hardness of a surface layer, is possible.

1. Introduction
Laser processing of materials are of great importance as it provides substantial increase of quality and operational characteristics of the details. The laser processing impact on structure of a surface layer, on local annealing of thin films, their optical and electric properties, on formation of thin coverings is studied in [1-5].

Surface morphology during laser heating of metal powders, feature of the melted surface, mechanisms of porous formation, flow simulations of liquid and a heat transfer at laser processing are investigated [6-15].

Formation of operational properties including a hardness of the processed surface layer under the influence of the power of laser radiation have been discussed not only for steel details but also other metals and alloys [16-20].

Noted scientific works contain single-factor mathematical models, which explain mechanisms and physical essence of the current processes.

Together with it for manufacturing enterprises during implementation of laser technologies it is important to have the multiple-factor experimental models, which connect technological independent factors with parameters of quality of the processed surface layer.
2. Materials and methods

Laser processing of chromic steel 40H13 is carried out on a modern multibeam complex, wavelength – 10.6 micrometers, diameter of a contact spot of a laser beam with workpiece – 10 mm.

As independent entrance factors of process are chosen: power of laser radiation $W$ (x1 code), longitudinal feed $Spr(x2)$, distance $L$ (x3) from protective glass of a focusing head up to the processed surface of workpiece.

The top, main, lower level and also variation intervals of independent factors are presented in Table 1.

| Levels of factors | Power of radiation $W$, kW | Longitudinal feed $Spr$, mm/s | Distance $L$, mm |
|-------------------|-----------------------------|-------------------------------|-----------------|
| Code              | x1                          | x2                            | x3              |
| Top level         | 5.0                         | 25                            | 85.0            |
| Variation interval| 1.5                         | 7.5                           | 12.5            |
| Main level        | 3.5                         | 17.5                          | 72.5            |
| Lower level       | 2.0                         | 10                            | 60.0            |

As the optimization parameter the hardness $Hv(Y)$, defining operational indicators of a product, is chosen. A priori the postulated mathematical model was found in the form of a polynom:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3,$$

(1)

where $b_0 - b_3$ - regression coefficients; $x_1 - x_3$ – independent factors of laser processing in code designation.

Hardness of the processed surface layer of samples was measured on the Micro-Combi Tester installation of CSM Instruments (Switzerland), which allows to determine the hardness, the elasticity module and other characteristics of the studied material.

3. Results

Results of realization of a planning matrix of a multiple-factor experiment (Table 2) serve as initial information for statistical processing and definition of multiple-factor model of hardness of a surface layer.

| Factors          | Parameter |
|------------------|-----------|
| Power of radiation $W$, kW | Longitudinal feed $Spr$, mm/s | Distance $L$, mm | Hardness, MPa |
| $x_1$            | $x_2$    | $x_3$  | $Hv$   |
| 5                | 25       | 85     | 627    |
| 2                | 25       | 85     | 195    |
| 5                | 10       | 85     | 478    |
| 2                | 10       | 85     | 602    |
| 5                | 25       | 60     | 349    |
| 2                | 25       | 60     | 324    |
| 5                | 10       | 60     | 441    |
| 2                | 10       | 60     | 302    |

Arithmetic averages values of hardness $Hv$ of a surface layer for every matrix line are situated in an extreme right column of Table 2.
Interactive influence of laser radiation power $W$ and longitudinal feed $Spr$ of a laser beam on hardness of the processed surface layer is characterized by the regression equation:

$$H_v = 372.8 + 39.3(W) - 5.47(Spr).$$  

(2)

Graphic interpretation of (2) is presented in Fig. 1.

**Figure 1.** 3M-XYZ surface-schedule of interactive influence of radiation power $W$ and longitudinal feed $Spr$ of a laser beam on hardness of surface layer.

3M-XYZ the contour-schedule of interactive influence of factors $W$ and $Spr$ on the hardness of a surface layer of steel 40H13 is presented in Fig. 2.

**Figure 2.** 3M-XYZ contour-schedule of interactive influence of radiation power $W$ and longitudinal feed $Spr$ of a laser beam on hardness of surface layer.

Interactive influence of radiation power $W$ and distance $L$ from protective glass to the processed surface of workpiece on the hardness of a surface layer is described by the regression equation:

$$H_v = -75.27 + 39.3(W) + 4.86(L).$$  

(3)

Graphic interpretation of (3) is presented in Fig. 3.
Figure 3. 3M-XYZ surface-schedule of interactive influence of radiation power $W$ and distance $L$ from protective glass to the processed surface on the hardness of the surface layer.

3M-XYZ contour-schedule of interactive influence of factors $W$ and $L$ on hardness of the processed surface layer of steel 40H13 is presented in Fig. 4.

Interactive influence of longitudinal feed $Spr$ of a laser beam and distance $L$ from protective glass to the processed surface on the hardness of a surface layer is described by the regression equation:

$$Hv = 158.1 - 5.47*Spr + 4.86*L.$$  \hspace{1cm} (4)

Graphic interpretation of (4) is presented in Fig. 5.
Figure 5. 3M-XYZ surface-schedule of interactive influence of factors Spr and L on the surface layer hardness.

3M-XYZ contour-schedule of interactive influence of longitudinal feed Spr of a laser beam and distance L from protective glass to the processed surface of workpiece on the hardness of the processed surface layer is presented in Fig. 6.

Figure 6. 3M-XYZ the contour-schedule of interactive influence of factors Spr and L on hardness.

The regression equation, which describes surface layer hardness in code designation of factors and optimization parameter and which includes all factors of process, has a view:

$$Y = 414.75 + 59.0x_1 - 41.0x_2 + 60.75x_3.$$  \hspace{1cm} (5)

The regression equation in natural designation of factors and optimization parameter, which includes all factors of process, has a view:

$$Hv = 295.6 + 39.3W - 5.47Spr + 4.86L.$$  \hspace{1cm} (6)

The regression equations (2)-(4) and (6) allow to appoint of the technological modes of laser processing, providing the required hardness of surface layer of steel 40H13, what confirms their relevance for production.
4. Discussion
Statistical data processing allowed us not only to obtain regression equations linking the optimization parameter \( H_v \) with independent factors of laser processing, but also to present a graphical interpretation of these equations, which increases the information content of research and simplifies the assignment of laser processing modes.

It follows from (5) that the power of laser radiation increases the hardness of surface layer and has the greatest effect on it. According to the degree of influence on the hardness of the distance \( L \) (within its values) is in second place and with increasing distance, the hardness of the surface layer also increases. As the longitudinal feed of the laser beam increases, the hardness decreases, and this factor has the least effect on the optimization parameter. This influence of factors is explained by the degree of their thermal effect on the surface layer of the sample.

The research results allow not only to quickly assign laser processing modes, but also provide a scientific basis for the design of new technological laser complexes.

Conclusion
1. The analysis of prior information in the field of laser treatment of metals and alloys showed, that due attention was not paid to development of multiple-factor experimental models, on the basis of which an appointment and optimization of the processing modes are possible. This fact demands additional experiments in production conditions and increases a technological prime cost of products.

2. The multiple-factor experimental model of a hardness of surface layer of steel 40H13, processed by multibeam laser, consists of several regression equations, which connect entrance factors of process (radiation power, longitudinal feed of a laser beam and a distance from protective glass of a focusing head up to workpiece) with a hardness of surface layer and the modes of laser processing. Noted model allows to appoint quickly the modes of laser processing.

3. The executed graphic interpretation of the regression equations and multiple-factor model are relevant not only for the manufacturing enterprises, realizing modern laser technologies, but also for the organizations, which design laser equipment for technological using.

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