Multiple-Factor Model of Hardness of Steel 40x13 After Laser Processing

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MULTIPLE-FACTOR MODEL OF HARDNESS OF STEEL 40X13 AFTER LASER PROCESSING

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Abstract. The multiple-factor experiment is planned and made, and the hardness of the chromic steel 40X13, 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 sample and a distance from protective glass of a laser 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 numerical values of hardness of a surface layer, is possible.

Keywords: Laser processing, Hardness, Multiple-factor model, Graphic interpretation, Processing mode, Surface layer.

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 [1-5] etc.

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 and so on are investigated [6-15]. Formation of operational properties including

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a hardness of the processed surface layer under the influence of the power of laser radiation are made not only for steel details but also other metals and alloys [16-20].

Noted scientific works contain 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.

When using multiple-factor model the appointment of the modes of laser processing comes down to the elementary choice of entrance factors of process according to this model and its graphic interpretation what excludes performance of additional experiments in production conditions and reduces the technological cost of details. From such point of view the due attention was not paid to processes modeling of laser processing

The purpose of research - development of experimental the multiple-factor model, which allows to appoint and optimize the technological modes of laser processing taking into account requirements to hardness of the processed surface layer.

2. Research technique

Laser processing of chromic steel 40X13 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 (x_1 code), longitudinal feed Spr(x_2), distance of L (x_3) from protective glass of a laser head up to the processed surface of workpiece. The top, main, lower level and also variation intervals of independent factors are presented in tab. 1.

Table 1. Levels and intervals of variation of factors subsubsections.

Levels of factors	Power of radiation W, kW	Longitudinal feed Spr, mm / s	Distance L, mm
Code	x_1	x_2	x_3
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:

$$\mathrm{Y} = b_0 + b_1x_1 + b_2x_2 + b_3x_3\ , \tag{1}$$

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. Realization results of a planning matrix of a multiple-factor experiment

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

Table 2. Results of multiple-factor experiment

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 tab. 2.

4. The regression equations and their graphic interpretation

Statistical data processing allowed not only to receive the regression equations, which connect the optimization parameter Hv with independent factors of laser processing, but also to present graphic interpretation of these equations, what increases the information content of researches and simplifies an appointment of the modes of laser processing.

Interactive influence of laser radiation power W and longitudinal feed Spr of a beam on hardness of the processed surface layer is characterized by the regression equation:

$$Hv = 372{,}8 + 39{,}3(3) * W - 5{,}47 * Spr. \qquad (2)$$

Graphic interpretation (2) is presented in fig. 1.

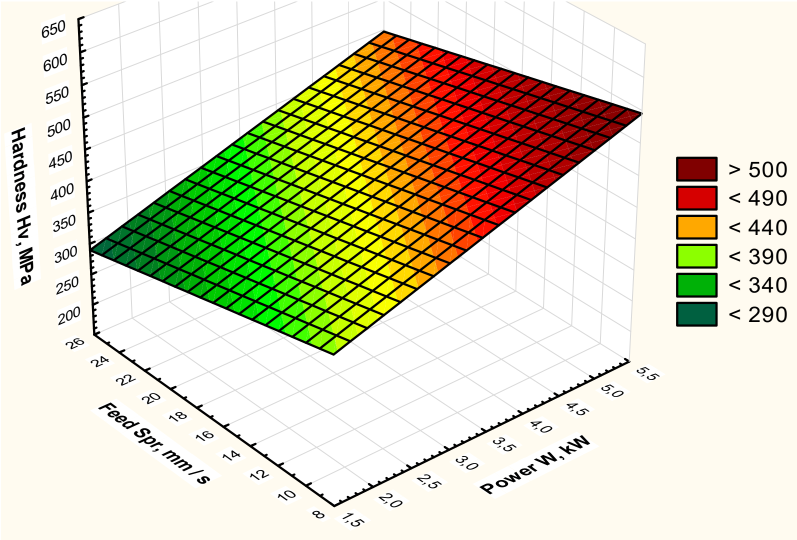

Fig. 1. 3M-XYZ the surface-schedule of interactive influence of radiation power W and longitudinal feed Spr of a laser beam on hardness of surface layer.

3M-XYZ the contour-schedule of interactive influence of factors W and Spr on the hardness of a surface layer of steel 40X13 is presented in fig. 2.

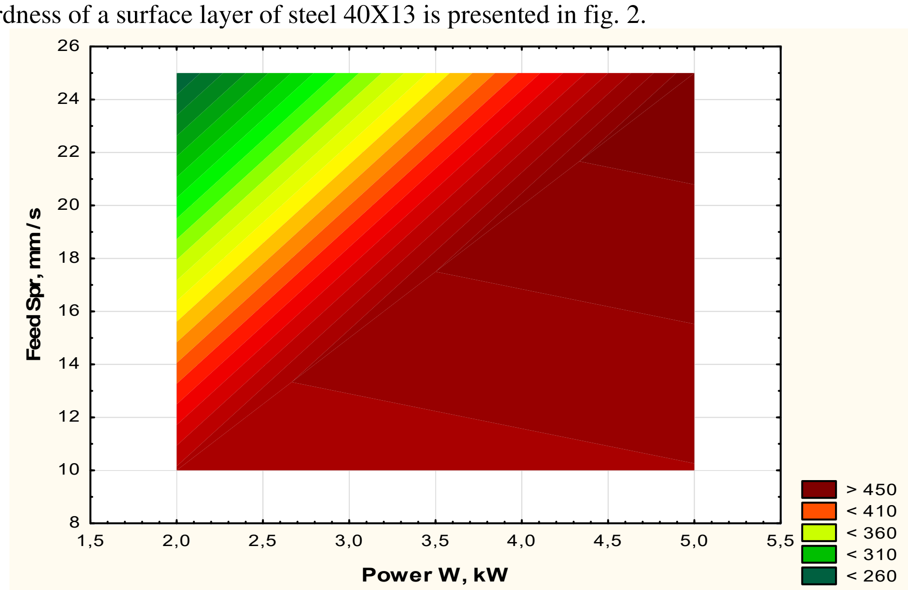

Fig. 2. 3M-XYZ the contour-schedule of interactive influence of radiation power W and longitudinal feed Spr of a laser beam on hardness of surface layer.

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:

$$Hv = -75{,}27 + 39{,}3(3)*W + 4{,}86*L \qquad (3)$$

Graphic interpretation of (3) is presented in fig. 3.

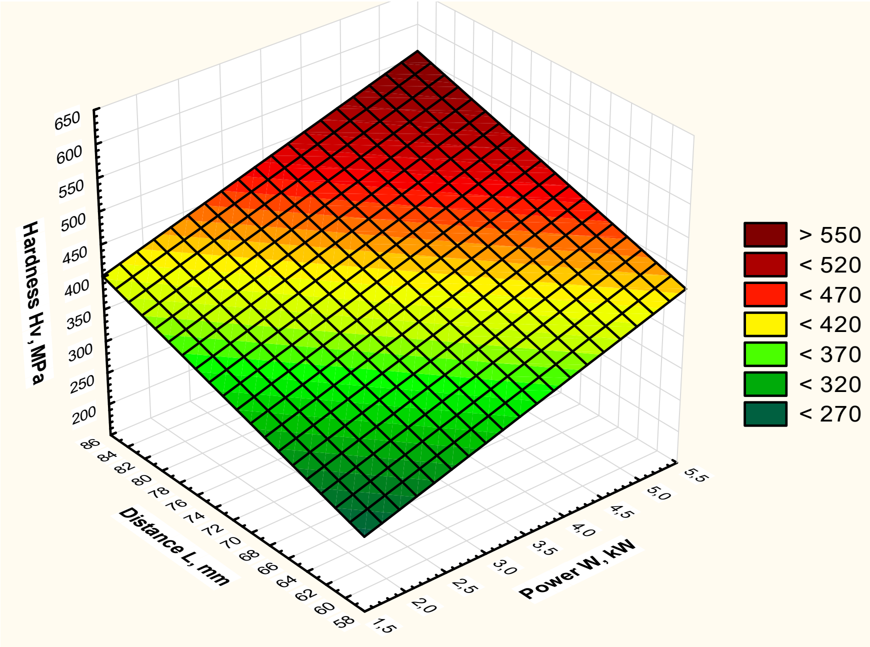

Fig. 3. 3M-XYZ the surface schedule of interactive influence of radiation power W and distance L from protective glass to the processed surface on the hardness of the surface layer.

3M-XYZ the contour-schedule of interactive influence of factors W and L on hardness of the processed surface layer of steel 40X13 is presented in fig. 4.

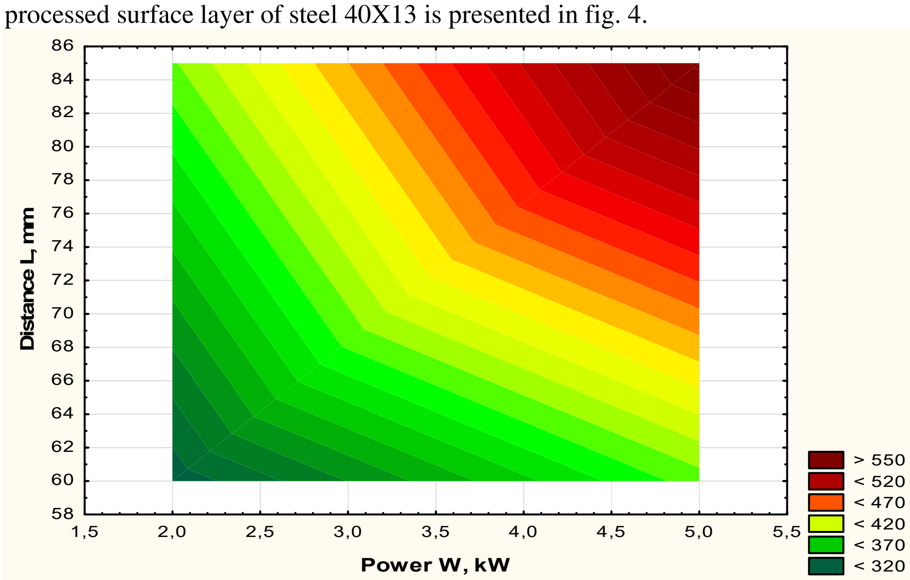

Fig. 4. 3M-XYZ the contour-schedule of interactive influence of factors W and L on surface layer hardness.

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:

$$Hv = 158{,}1 - 5{,}47 * S_{пр} + 4{,}86 * L \tag{4}$$

Graphic interpretation of (4) is presented in fig. 5.

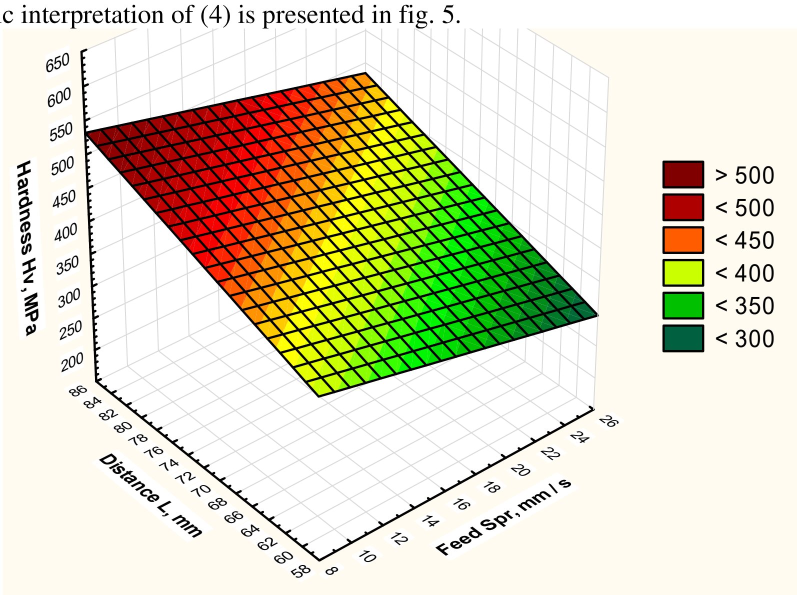

Fig. 5. 3M-XYZ the surface-schedule of interactive influence of factors Spr and L on the surface layer hardness.

3M-XYZ the contour-chedule of interactive influence of longitudinal feed 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.

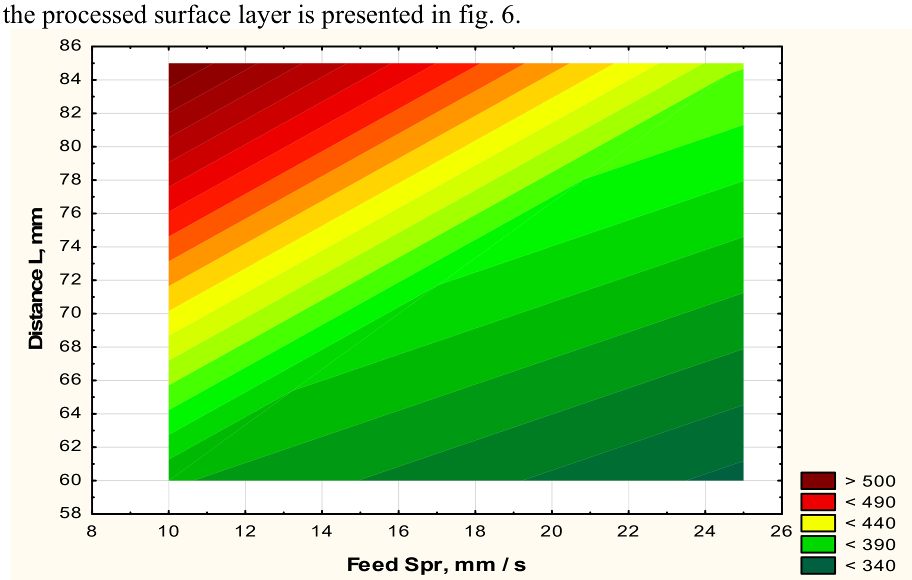

Fig. 6. 3M-XYZ the contour-schedule of interactive influence of factors Spr and L on surface layer hardness.

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

$$Y = 414{,}75+59{,}0*x_1 - 41*x_2+60{,}75*x_3 \tag{5}$$

From (5) follows, that the power of laser radiation increases the hardnes and has the greatest impact on it. On extent of influence on hardness the distance L (within its values) is on the second place and with increase of distance the surface layer hardness also increases. At increase of longitudinal feed of a laser beam the hardness decreases, and this factor has the smallest impact on the optimization parameter. Such influence is explained by extent of thermal impact of a factor on a surface layer of sample.

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

$$Hv = 295,6 + 39,3*W - 5,47*S_{np} + 4,86L \qquad (6)$$

The regression equations (2)-(4) and (6) allow to to appoint numerical values of the technological modes of laser processing, providing the required hardness of surface layer of steel 40X13, what confirms their relevance for production.

Thus, as a result of the executed researches the multiple-factor experimental model of a surface layer hardness after laser processing of steel 40X13, and also graphic interpretation of the regression equations are received. The reserch results allow not only to appoint quickly the modes of laser processing, but also are scientific base for 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 40X13, 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 laser head up to workpiece) with a hardness of surface layer and the modes of laser processing. Noted model allows to appoint queckly 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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