The choice of pulse laser radiation modes for hardening a metal cutting saw

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Abstract. Increasing production rates of parts, toughening of operation modes and load increasing, reduce the service life of equipment. The destruction of the tool usually begins with the surface, so its strengthening is one of the main factors of improving the resource and reliability. Hardening the working surfaces with laser radiation is the most effective and promising method of hardening tools that are used under friction conditions. This article presents the results of experimental study of the laser hardening process of a band saw made of 9CrV tool steel; a mathematical model based on these experiments was made to show the connection of the parameters of pulse laser radiation and the depth of the resulting hardened area. It shows that the pulse energy and the movement speed for pulse laser hardening with the chosen parameters have a decisive influence on the depth of the hardened area.

Different ways to increase the resistance and strength was developed to improve the service life of machine parts, mechanisms and tools. Together with traditional methods of surface hardening such as thermal, chemical and thermal, electric-spark etc., technologies using concentrated energy sources such as laser beams are becoming more widespread nowadays [1]. Pulse laser radiation is of particular value, it helps to control the energy at the treated surface and as a result, the mechanical properties of the surface.

The term "laser hardening" is a physical process developing as a result of laser thermal effects. The intense laser flux is absorbed by the surface layer. It changes the structure that depends on the treatment modes and physical properties of the treated materials. Therefore the term "laser hardening" is a process of changing the structure and sensitive mechanical properties of materials and alloys. Mechanical properties are structurally sensitive, so special attention is paid to the regularities of structure formation under different condition and laser treatment modes [2].

It is known that surface laser hardening is a promising method of hardening tools with limited resistance [3,4]. After laser exposure the structure of the material has a high dispersion, so the coefficient of friction decreases and microhardness increases. All these factors have a positive effect on the product resistance. Therefore surface hardening is important for treatment and reducing wear of band saws and cutting edges of different tools [5].

The quality parameters of the hardened surface layer depend on the temperature and time characteristics of pulse laser radiation. While changing these parameters, it is possible to form a surface layer with the specified hardness and structure. Pulse laser treatment does not change the geometry of the heated area; it retains the quality of the main mass of metal, which is heated together with the surface.
layer. It creates prospects for the use of laser methods in technological processes of surface hardening without further grinding.

In spite of good prospects, the technological process of laser treatment in the industry is not widely used. This is due to economic difficulties of the enterprise, where it is desirable to implement them, the lack of technological knowledge of obtaining coatings and issues of their performance properties for different working conditions [6].

This article is relevant due to the necessity of studying the scientific foundations, development of technologies of pulse laser hardening, the influence of technological parameters on the structure and properties of hardened surfaces of band saw tools [7,8].

The purpose of this article is to study the impact of pulse laser radiation on the structure and surface properties of band saws made of 9CrV steel and to establish a mathematical relationship between the modes of pulse laser radiation and the depth of the hardened area.

The object of this article is laser hardening of 9CrV band saw steel at a machine with a solid-state ND+3:YAG-crystal laser.

Solving the tasks set in the article, the following methods were used: mechanical testing, metallography, methods of mathematical statistics for processing experimental data and full factorial experiment.

Statistical analysis of experimental data was performed with MS Excel software based on the theoretical recommendations given in the article [9]. A full factorial experiment was planned and made to study the influence of three main factors (laser power density, laser pulse frequency and laser head speed).

To find the optimal laser hardening modes influencing the quality of hardening, a complete factorial experiment was made in this article, taking into account the influence of three main production factors: the movement speed \( v \), the pulse repetition frequency \( f \) and the energy of the laser pulse \( W \). The measured value \( y \) is the depth of the hardened layer. The pump current \( I = 50 \) A is the free term \( x_0 \). The constant parameter is the diameter of the focused laser radiation \( d=1 \) mm.

The conditions of the experiment were determined based on the preliminary experiment and analysis of the current state of the problem under study. They are presented at a normalized scale in Table 1.

| Characteristic          | \( x_1 = W \), J | \( x_2 = f \), Hz | \( x_3 = v \), mm/min |
|------------------------|-----------------|------------------|----------------------|
| zero level             | 2.75            | 30               | 500                  |
| variability interval   | 2.25            | 10               | 200                  |
| upper level            | 5.0             | 40               | 700                  |
| lower level            | 0.5             | 20               | 300                  |

The complete factorial experiment planned on the basis of the methodological recommendations given in the article [9] is presented in Table 2.

In general the mathematical model in the form of a multiple regression equation is presented as follows:

\[
y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 + b_{123} x_1 x_2 x_3
\]

To avoid systematic errors the sequence of parallel experiments was determined by randomization. To compensate the influence of random errors, each experiment was repeated \( n = 4 \) times.

The dispersion homogeneity was checked with the Cochrane criterion. The least squares method was used to calculate the coefficients of the regression equation. The hypothesis about the static significance of regression coefficients was made with the Student's test.

The obtained mathematical model was assessed with Fischer criterion.
Table 2. Expanded experiment planning matrix.

| №  | x0 | x1 | x2 | x3 | x1x2 | x1x3 | x2x3 | x1x2x3 | W, J | f, Hz | v, mm/sec | y, mm |
|----|----|----|----|----|-------|-------|-------|--------|------|------|----------|-------|
| 1  | +  | -  | -  | +  | +    | +     | -     | 0.50   | 20   | 5.00 | 0.28     | 0.25  |
| 2  | +  | +  | -  | -  | -    | +     | +     | 5.00   | 20   | 5.00 | 1.4      | 1.49  |
| 3  | +  | -  | +  | -  | -    | +     | -     | 0.50   | 40   | 5.00 | 0.35     | 0.32  |
| 4  | +  | +  | -  | -  | -    | -     | -     | 5.00   | 40   | 5.00 | 1.54     | 1.61  |
| 5  | +  | -  | -  | +  | +    | -     | -     | 0.50   | 20   | 11.67| 0.07     | 0.04  |
| 6  | +  | +  | -  | +  | -    | +     | -     | 5.00   | 20   | 11.67| 1.12     | 1.12  |
| 7  | +  | -  | +  | +  | -    | +     | -     | 0.50   | 40   | 11.67| 0.14     | 0.14  |
| 8  | +  | +  | +  | +  | +    | +     | +     | 5.00   | 40   | 11.67| 1.47     | 1.42  |

As a result of statistical treatment of experimental data, the dispersion homogeneity of the samples was confirmed, i.e. a correlation between the values under consideration. The results of coefficients calculation of the regression equation are shown in Table 3. The significance of the regression coefficient is marked with a "+" sign in Table 3.

Table 3. Coefficients of the regression equation.

|    | b0  | b1  | b2  | b3  | b12  | b13  | b23  | b123 |
|----|-----|-----|-----|-----|------|------|------|------|
|    | 0.78| 0.61| 0.05| -0.11| 0.02 | 0.00 | 0.03 | 0.04 |

| tS0 | tS1 | tS2 | tS3 | tS4 | tS5 | tS6 | tS7 |
|-----|-----|-----|-----|-----|-----|-----|-----|
| 31.55 | 24.63 | 2.19 | 4.55 | 0.95 | 0.11 | 1.36 | 1.54 |

Student’s coefficient $t_S$ for 4 measurements with a confidence interval 95%.

$t_S > t_{S8} = 3.18$

The final mathematical model is presented as follows:

$$y = 0.78 + 0.61 \cdot x_1 - 0.11 \cdot x_3$$

The analysis made according to Fischer criterion gave a positive result.

Conclusions

Based on the obtained mathematical model, it was found that it is possible to adjust the depth of the hardened area of band metalworking saws by varying the parameters of the pulse energy and the movement speed. The frequency of pulse repetition in the chosen range does not have a significant statistical effect. As the pulse energy increases, the temperatures in the laser beam areas increase and the depth of the hardened area increases. While the movement speed of the laser head affects the time...
of exposure to laser radiation; the higher is its value, the lower is the depth of the hardened area. However as the speed increases, the absolute values of surface hardness are higher.

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