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Experimental Studies of Roughness by Surface Plastic Deformation on Flat Surfaces

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***Abstract*—The article presents experimental studies of the roughness by surface plastic deformation (SPD) on flat surfaces of steel 45. A dispersion analysis was used to study the influence of various factors on the surface quality. From the experimental studies and the dispersion analysis made, a graphical interpretation of the main effects was obtained. Graphical visualizations of the roughness pattern after SPD on the processed surfaces were obtained. Overlapping sinusoidal movements of the deforming spherical element were realized.**

Keywords—surface plastic deformation, roughness, flat surfaces.

I. Introduction

The loss of machinability of the machine parts usually occurs after the surface layer has been destroyed. It has been found that the functional purpose of various machine-building products depends to a large extent on the qualitative indicators of the surfaces.

One of the simplest and most common methods for controlling a wide range of Surface Layer Quality Parameters is the finishing treatment by surface plastic deformation (SPD).

One of the ways to improve the quality of production is the use of surface plastic deformation processing methods [1]. The advantage of the SPD is a capability to combine effects of finishing and strengthening treatment. In the literature, there is a wide variety of methods for finishing by surface plastic deformation, having a number of specific features [3] – [4]. The most complete and systematic methods for surface elastic deformation are discussed in [2]. In [5] prepared a review of the methods of plastic deformation of matrices and punches.

At the same time, there is no scientifically based methodology allowing the selection of optimal working conditions to ensure the specified quality of the parts.

The purpose of the present work is to perform experimental studies to determine the influence of the geometrical, technological and energetic parameters of the surface plastic deformation on the roughness of the machining surfaces.

II. General Regulations

In order to study the influence of the technological parameters of the SPD process on the roughness of the processed surfaces, a number of experimental studies were carried out.

The flat surfaces of steel 45 with chemical composition according to Table 1 are face milling [6]. Sinusoidal overlapping movements with a ball deforming tool have been realized by changing the process parameters of the SPD process.

Table 1 Chemical compositionab of steel 45

C	Si	Mn	P	S	Cr	Ni
%	%	%	%	%	%	%
0,45	0,26	0,63	0,035	0,040	0,20	0,20

The tests were carried out on a drilling machine PB 501. The processed specimens were fastened on the machine table and the ball-forming tool of the vertical spindle The roughness of the specimens after each experiment was measured with a Mitutoyo Surftest - 4 profiles shaper at two lengths, averaging the arithmetic roughness (Fig. 1). A multifactorial dispersion analysis was performed in order to quantify the influence of the factors and regression analysis of the experimental results obtained from the experimental plan.

Fig. 1. Roughness measurement.

The levels of variability of the control factors are shown in table. 2 and were selected on the basis of experimental pre-planning results.

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TABLE 2 FACTORS, LEVELS

Factors		**Levels of factors**		
	coded			
	-1	**0**	**+1**	
natural	**coded**	**natural**		
Force of pressing of the ball to the part F_b, N	x_1	100	300	500
Radius of the deforming ball tool r, mm	x_2	5	10	15
Feed f, $mm/\min$	x_3	100	900	1500
Number of the cuts N	x_4	1	2	3
Initial roughness R_a^n, μm	x_5	1	3	5

The results of the preliminary experiments show that the models are non-linear. For this reason an optimal composition plan has been chosen.

Since the factors are 5, the number of experimental points increases to $N = 2^5 + 2 \times 5 = 42$. To reduce attempts, the centre of the plan is chosen to be a fractional replica with $t = 3$, that is, the number of attempts in the kernel of the plan is $N_{yäðî} = 2^{5-3} = 4$. The optimal one-point composite plan was synthesized by QStatlab [8]. The impact of various factors on surface quality was investigated by dispersion analysis. From the experimental studies and the multifactor dispersion analysis, a graphical interpretation of the major factors was obtained (Fig. 2).

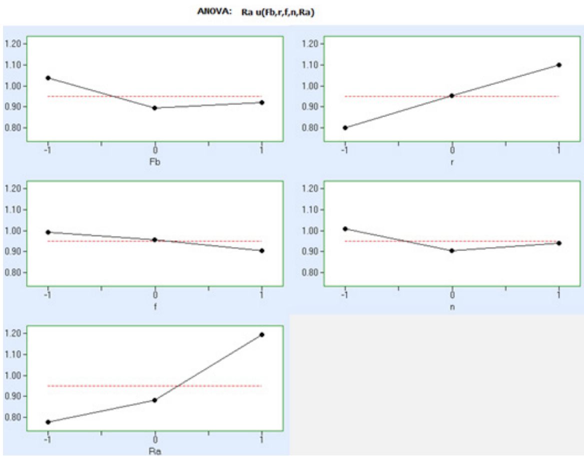

Fig. 2. Overview of the main effects (significance of the factors).

From Fig. 2 it follows that in order to maintain a maximum level of the quality indicator (in this case it is minimal roughness) it is necessary to maintain the 5 factors at the respective levels shown in table. 3. Obviously, reducing the diameter of the ball achieves a reduction in roughness. The impact of the initial roughness is strongest, and the impact of the feed is minimal.

TABLE 3. LEVELS OF FACTORS

Factor	x_1	x_2	x_3	x_4	x_5
Level	lower	upper	lower	lower	upper

Given the fact that the plan is second order (optimal compositional), the regression model is chosen to be a second order polynomial to allow for a correct statistical analysis [7]:

$$Y_{R_a}(x_1, ..., x_6) = b_0 + \sum_{i=1}^{k} b_i x_i + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} x_i x_j + + \sum_{i=1}^{k} b_{ii} x_i^2, \quad (1)$$

where Y_{R_a} is the target function of the obtained roughness R_a with the arguments of the coded factors.

Coefficients estimates $b_0, b_1, ..., b_{44}, ...$ are obtained from the matrix multiplications:

$$\{b\} = \left([F]^T [F]\right)^{-1} [F]^T \{R_{a,u}\}, \quad (2)$$

where $\{b\}$ is the vector of the quoted coefficients in the model, $[F]$ is an extended matrix of the plan, $\{R_{a,u}\}$ is the vector of the experimental values of the target function Y_{R_a}.

The resulting regression model is

$$Y_{R_a} = 0.850 - 0.347x_2 + 0.302x_3 - 0.167x_5 - -0.122x_1x_2 + 0.648x_2^2 + 0.234x_3x_5 - -0.475x_4^2 - 0.241x_4x_5$$

The detailed scan of the obtained model indicates the existence of areas with negative values for the roughness, although the polynomial is of the second degree, and the selected coefficients are significant. For this reason, this roughness model can only be used in area of experimental points to predict roughness, but is not suitable for use in optimization procedures.

The visualization of the main effects (Fig. 3) shows that the influence of the individual factors can be linearized. Based on the plan centre and one central point, the following linear regression model was obtained:

$$Y_{R_a} = 0.952 + 0.122x_1 - 0.222x_2 + 0.26x_3 + +0.048x_4 - 0.14x_5 + 0.079x_1x_4 + 0.07x_1x_6 - -0.09x_2x_3 + 0.076x_2x_4 + 0.048x_2x_5 - 0.144x_2x_5 - -0.105x_3x_4 + 0.152x_3x_5 - 0.075x_4x_5 \quad (3)$$

An object of analysis is the model (3).

The relation between encoded (single) x_1 and natural factors $\tilde{x}_1$ is

$$x_1 = (\tilde{x}_1 - \tilde{x}_{0,1}) / \lambda_1, \quad (4)$$

where

$$\lambda_1 = (\tilde{x}_{a,1} - \tilde{x}_{a,1}) / 2 \quad (5)$$

$\tilde{x}_{0,l}$, $\tilde{x}_{a,l}$ and $\tilde{x}_{a,l}$ are respectively the average, upper and lower levels of the l-s natural factor.

After replacing (4) and (5) in (3), the expression of roughness with natural factors is obtained. The results of the analysis are shown in Fig. 3 in the form of three-dimensional graphs.

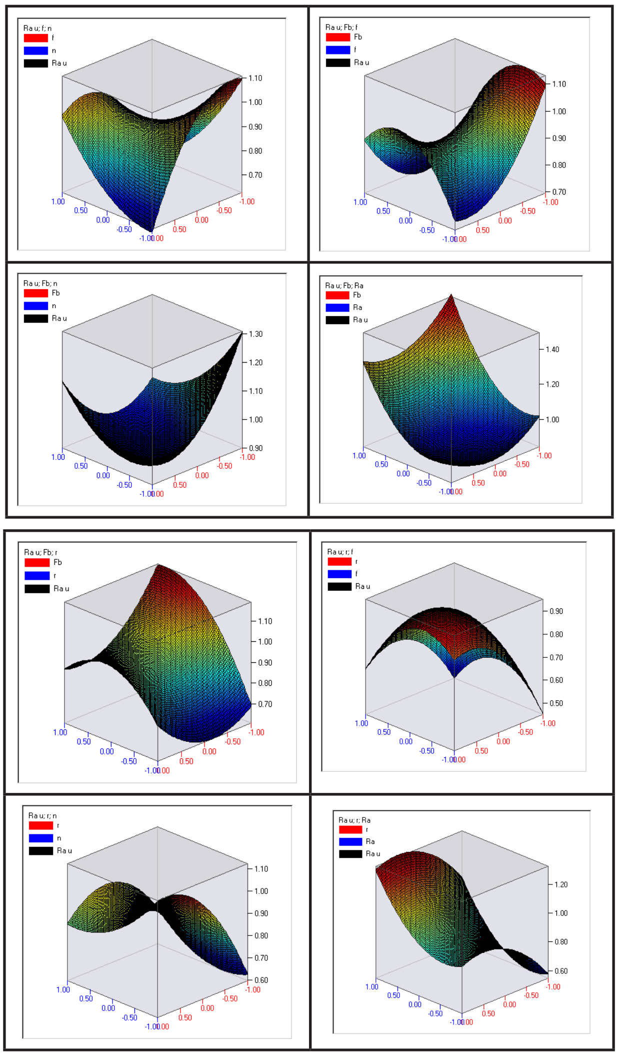

Fig. 3. Three-dimensional graphs of roughness function Y_{R_a} .

III. Conclusions

The resulting graphical visualizations of the roughness pattern model after the SPD of the treated flat surfaces (Fig. 3) confirm the conclusions about the influence, significance and the levels of the factors on the surface qualitative indicators.

The detailed scan of the obtained model indicates the existence of areas with negative values for the roughness, although the polynomial is of the second degree, and the selected coefficients are significant. For this reason, this roughness model can only be used in area of experimental points to predict roughness, but is not suitable for use in optimization procedures.

The implementation of small feeds, a high deformation force and a lower initial roughness lead to an improvement in the qualities of the treated surfaces and greatly reduce the roughness.

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