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DETERMINATION OF OPTIMAL BALL BURNISHING PARAMETERS FOR SURFACE HARDNESS

DOLOČITEV OPTIMALNIH PARAMETROV KROGLIČNEGA GLAJENJA ZA POVEČANJE TRDOTE POVRŠINE

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The objective of this study is to improve surface hardness of 7178 aluminum alloy using the ball burnishing process. The effect of the main burnishing parameters on the objective function was examined using full factorial design and analysis of variance (ANOVA). The main parameters were found as burnishing force, feed rate and number of passes among four controllable factors that influence the surface hardness in ball burnishing process. Optimal ball burnishing parameters were determined after the experiments of the Taguchi's L9 orthogonal array. As result, the optimal burnishing parameters for surface hardness were the combination of the burnishing force at 200 N, number of passes at 4, feed rate at 0.25 mm/r.

Key words: Ball burnishing, surface hardness, Taguchi technique, factorial design, ANOVA

Cilj tega dela je bil povečati trdoto aluminijeve zalitine 7178 s krogličnim glajenjem. Vpliv glavnih parametrov glajenja na trdoto je bil opredeljen z uporabo polnega faktorialnega načrtovanja in analizo variance (ANOVA). Štirje glavni parametri glajenja, ki vplivajo na trdoto površine, so sila glajenja, hitrost podajanja in število prehodov. Optimalne parametre glajenja smo določili z ortogonalno razporeditvijo Taguchi L9. Končni rezultat so naslednji optimalni parametri: sila glajenja 200 N, število prehodov 4 in podajanje 0,25 mm/r.

Ključne besede: kroglično glajenje, trdota površine, Taguchijeva metoda, faktorialno načrtovanje, ANOVA

1 INTRODUCTION

The burnishing of metals is a cold-working process that leads to an accurate change on the surface profile of the workpiece by a minor amount of plastic deformation. In burnishing process, surface irregularities is redistributed without material loss [1–2]. The burnishing process gives many advantages in comparison with chip-removal processes. Burnishing increases the surface hardness of the workpiece, which in turn improves wear resistance, increases corrosion resistance, improves tensile strength, maintains dimensional stability and improves the fatigue strength by inducing residual compressive stresses in the surface of the workpiece [3–6].

A survey of references shows that work on burnishing has been conducted by many researchers. Esme et al. [7] developed an artificial neural network model for the prediction surface roughness of AA 7075 aluminum alloy in ball burnishing process. Yan et al [8] investigated the feasibility and optimization of a rotary electrical discharge machining with ball burnishing for inspecting the machinability of Al_2O_3/6061 Al composite using Taguchi method. Shiou and Chen [9] examined ball burnishing surface finish of a freeform surface plastic injection mold on a machining centre by using Taguchi techniques. Seemikery et al. [10] focused on the surface roughness, micro-hardness, surface integrity and fatique life aspects of AISI 1045 work material using full factorial design of experiments. Hassan et al. [11] investigated the effect of the burnishing force and number of passes on the surface roughness using Response Surface Methodology (RSM). El-Axir et al. [12] studied the surface finishing of 2014 aluminum alloy by using RSM with central composite design in ball burnishing process. El-Axir [13] determined the optimum combination of burnishing parameters to improve surface integrity for 6061 aluminum alloy applying a vertical milling machine using RSM with central composite design.

In this study, a factorial design and ANOVA were used to find out the effect of the main ball burnishing parameters. Taguchi's orthogonal array method was applied to determine the optimum levels of burnishing process parameters.

2 EXPERIMENTAL WORK

For experimental work, 7178 aluminum alloy was used as workpiece materials. Experiments were conducted on the different burnishing parameters and no coolant was used. The burnishing tool was mounted on tool holder of the CNC lathe. The workpiece was clamped by the three jaw chuck and tailstock centre of the machine. Three replications of each factor level combinations were conducted. Hardness measurements were made by using Zwick hardness tester.

The effect of several parameters can be determined efficiently with matrix experiments using factorial design and the analysis of variances was employed to

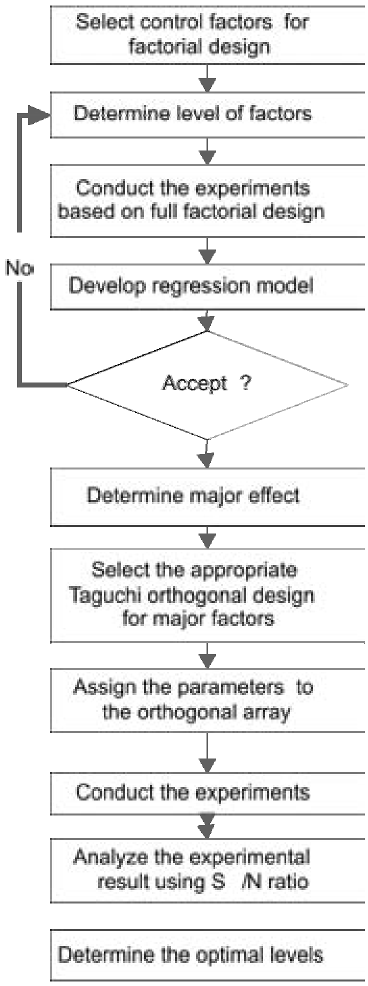

Figure 1: A flowchart of proposed methods
Slika 1: Potek uporabljenih metod

find the significance of the factor effects. Taguchi's design method was applied to determine the optimal levels of burnishing process. A flowchart of proposed methods is shown in **Figure 1**.

The level of the factorial design is shown in **Table 1**. Two levels of control factors are referred to as low and high. Twenty experiments constitute the 2^4 factorial design with an added centre point repeated four times. Surface hardness was taken as output variable and burnishing force, burnishing speed, feed rate and number of passes were taken as input parameters for maximizing the surface hardness of the 7178 aluminum alloy.

Table 1: Levels of the factors for factorial design
Tabela 1: Nivoji faktorjev za faktorialno načrtovanje

Factors/Levels	Low (-1)	Centre (0)	High (+1)
Burnishing force/N	100	150	200
Speed/mm/min	33	52	71
Number of passes	2	3	4
Feed rate/mm/r	0,25	0,35	0,45

The Taguchi design concept a L9 mixed orthogonal arrays table was selected to conduct the matrix experiments for four level factors of ball burnishing process and designated in **Table 2**.

Table 2: Factors and levels for Taguchi design
Tabela 2: Faktorji in nivoji za Taguchijevo načrtovanje

Factors/Levels	1	2	3
Burnishing force/N	100	150	200
Number of passes	2	3	4
Feed rate/ mm/r	0.25	0.35	0.45

The optimization of the engineering design problems can be divided into the smaller-the better type, the nominal-the best type, the larger-the better type. The signal-to-noise (S/N) ratio is used as objective function for optimizing the product or process design [14]. The S/N ratio was chosen according to the criterion the-larger-the-better, in order to maximize the response. Based on the Taguchi method, S/N ratio is defined by the Equation 1.

$$\eta_j = -10 \lg \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \quad (1)$$

where: n is the number of experiment, y_i is the observations of the quality characteristic, n_j is the S/N ratio.

The optimization strategy of the larger the better problem is to maximize η defined with Equation 1. The levels that maximize η will be selected for the factors that have a significant effect on η and the optimal conditions for ball burnishing can then be determined. The predicted η_{opt} under optimal conditions could be calculated by using Equation 2

$$\eta_{opt} = m + \sum (m_i - m) \quad (2)$$

where: η_{opt} is the S/N ratio under the optimum conditions, m is the overall mean value of η for the experimental region, m_i is the η under optimal condition.

3 RESULTS AND DISCUSSION

The effect of selected process parameters on the surface hardness of aluminum alloy have been determined by using 2^4 full factorial design. ANOVA was employed to find the significance of the factor effects based on a 95 % confidence level. The ANOVA results are shown in **Table 3**.

The ANOVA table shows that, the most significant factors are the burnishing force and the number of passes, respectively, while feed rate is the less significant parameter of the ball burnishing process.

The optimum burnishing parameter combination was obtained by using Taguchi design and analysis of S/N ratio. **Table 4** shows experimental measurements made using the L9 orthogonal array based on the Taguchi method. Also, the S/N ratios were considered to evaluate the effect of burnishing parameters. The mean S/N ratio for each level of burnishing parameters is summarized in **Table 5** and it is shown graphically in **Figure 2**.

Table 3: The ANOVA results
Tabela 3: Rezultati ANOVA

Factor	**SS**	**df**	**MS**	***F***	***P***
Model	2740.	10	274.0	5.9	0.020
A	1242	1	1242.	26.	0.002
B	663.0	1	663.0	14.	0.009
C	333.0	1	333.0	7.1	0.036
D	52.56	1	52.56	1.1	0.328
AB	27.56	1	27.56	0.5	0.470
AC	45.56	1	45.56	0.9	0.359
AD	68.06	1	68.06	1.4	0.271
BC	33.06	1	33.06	0.7	0.430
BD	264.0	1	264.0	5.6	0.054
CD	10.56	1	10.56	0.2	0.650
Residual	278.3	6	46.39		
Pure error	4.50	1	4.50		
Cor total	3477	17			

A: Force, B: Speed, C: Number of passes, D: Feed rate
SS: Sum of square, df: Degrees of freedom, MS: Mean square

Table 4: Experimental results for surface hardness
Tabela 4: Rezultati preizkusov za trdoto površine

Experiment No	Burnishing Force/N	Number of passes	Feed rate/ mm/r	Surface hardness *HV*
1	100	2	0.25	167
2	100	3	0.35	170
3	100	4	0.45	179
4	150	2	0.45	175
5	150	3	0.25	179
6	150	4	0.35	181
7	200	2	0.35	178
8	200	3	0.45	192
9	200	4	0.25	202

Table 5: Mean S/N ratios for surface hardness
Tabela 5: Povprečna razmerja za trdoto površine

Factors/Levels	1	2	3
Burnishing Force	44.43	45.00	45.56
Number of passes	44.73	45.13	45.37
Feed rate	45.19	44.88	45.17

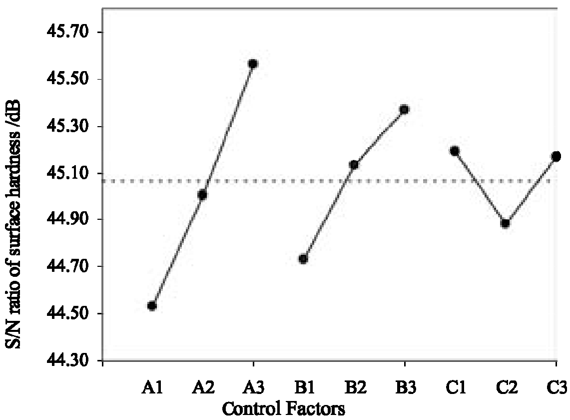

Figure 2: Plots of control factor effects
Slika 2: Grafični prikaz vpliva kontrolnih dejavnikov

The confirmation experiment was conducted at the optimum setting of the process parameters. The results of the confirmation experiment for surface hardness is given in **Table 6**.

Tabela 6: Rezultati potrditvenega preizkusa
Table 6: Results of the confirmation experiment

	Initial setup	Optimal condition	
		Prediction	Experiment
Level	A2B2C2	A3B3C1	A3B3C1
Hardness	175 HV		202 HV
S/N ratio	44.89 dB	45.79 dB	46.00 dB

The estimated S/N ratio using the optimal burnishing parameters for surface hardness was calculated using Equation 2. The predicted S/N ratio (45.79) is very close to the experimental S/N ratio (46.00) under optimal burnishing conditions. Based on the result of the confirmation test, the surface hardness is increased for 1.15 times.

4 CONCLUSIONS

In this experimental study, the effect "of the ball burnishing" parameters on surface hardness was examined and optimal settings of the ball burnishing parameters were obtained. The effect of several parameters can be determined efficiently with matrix experiments using factorial design. The main parameters were found as burnishing force, feed rate and number of passes among four controllable factors that affect the surface hardness in ball burnishing process. The burnishing force is the dominant factor, while, the number of passes is a major factor. The optimal burnishing parameters were determined with the Taguchi's L9 matrix experiments. The optimal parameter combination for the maximum surface hardness was obtained by using the analysis of S/N ratio. The optimal combination of experimental parameters for each factor is A3B3C1. As result, the optimal parameters for surface hardness were as follows: burnishing force at 200 N, number of passes at 4, feed rate at 0.25 mm/r.

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